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Application of Materials according to Mechanical Principles.

OUTLINES

OF

NATURAL PHILOSOPHY.

For the use of

SCHOOLS AND PRIVATE LEARNERS.

BY C. LIST.

ADAPTED

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PREFACE.

NATURE, to those who are unacquainted with the principles which science teaches, is a volume whose pages contain no entertainment nor instruction. But to those who can read it intelligently, every page of that volume is luminous with important disclosures, profound thoughts, and passages of sublime poetry.

If we did not know that there is a Universe, we should of course derive no intellectual enjoyment from its existence. The pleasure which Creation gives us is proportioned to the knowledge we have of the abundance of its supplies and the beauty of the operation of its laws. This knowledge, so essential to the happiness and proper developement of every mind, is imparted by the sciences.

The science of Mechanics, for instance, shows us that the whole universe is filled with beautiful applications of the laws of motion. By Acoustics we learn that the most unobserved sound has important relations to the most enchanting strains of music, and is the result of laws which are as extensive and enduring as physical existence; while Optics unfolds to us a lesson of wonders in every beam of light. Each of these, as we learn to comprehend it, presents to us, as it were, a new creation; and when we are satisfied with our researches in it, other sciences invite us on every side, and teach us that we need not, like Alexander, sigh for more worlds to conquer.

The practical effect of such studies will become obvious to the learner as he proceeds in them, and they are referred to in the preface to the "Outlines of Astronomy."

The present volume is too small to contain much of the information which is collected in larger works on the subjects of which it treats; but it is hoped that it will at least furnish a convenient alphabet to beginners in the study of the sciences.

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INTRODUCTION.

When we look around us in uncultivated places, we see clay, sand, rocks, streams, grass, shrubs, and trees, presenting an endless variety of forms and colors, and spread about apparently without any order.

When we pass through a village or city, we observe houses, churches, and other objects, all built according to some definite plan, and arranged with great regularity.

Now, however different the appearance in the two instances given, every stone, leaf, and other

object in nature, has its form and place assigned to it, according to certain rules, which are as invariable as those which guide the mason and carpenter in shaping and placing stones, beams, and other parts of buildings.

Those rules which govern the workman in producing a structure, a painting, or any thing else that is artificial, are called Rules of Art. Those which govern the existence and changes of natural objects, are called the Natural Laws, or the Laws of Nature.

It will require but little reflection to show us that it is not only pleasing, but vastly important to understand these laws. According to them the leaf falls, the bird sings, and the butterfly's wing is painted. According to them the streams flow, the rain falls, the wind blows, the lightning flashes, and the bow is spread out among the clouds. According to them the stars twinkle in the sky, the earth rolls in its orbit, and is warmed and lighted by the sun.

A knowledge of these laws enables us to bring rough materials out of the earth, and change them into articles of usefulness and beauty:—to make ourselves homes and to fill them with comforts; to sail in safety from country to country on the pathless ocean; to move along the surface of the ground at the rate of a mile in every minute; and to send invisible messages along lines of wire over hundreds of miles, in a time too short to be measured by the clock.

These examples will serve to show that every one should be acquainted at least to some extent with the laws of nature.

There are several departments of these: as the Moral Laws, or those which govern the actions of intelligent beings in reference to right and wrong—the Intellectual Laws, or those which govern what relates to the understanding and abstract truth—the Physiological Laws, or those which govern what relates to the principle of life in plants and animals—and the Physical Laws, or those which govern material nature.

What has been said of the operation of natural laws in this Introduction, has reference only to the last class, and to an explanation of them the following chapters will be devoted.

QUESTIONS.

How do objects in nature, at the first view, seem to be arranged?

How are those of villages and cities arranged?

Are natural objects, however, formed and placed according to certain rules or methods?

What are Rules of Art?

What are Natural Laws?

What is done in nature according to these laws?

What are we enabled to do by a knowledge of them?

What are the different kinds of natural laws?

Which of these is to be explained in this work?

CHAPTER I.

GENERAL PROPERTIES OF MATTER.

SECTION 2.

MATTER—IMPENETRABILITY—EXTENSION.

MATTER.

EVERY thing of which we can ascertain the existence by our senses, is composed of what we designate by the general name of Matter.

There are some properties which belong to all matter, in whatever form it may exist, and others which belong only to particular kinds of matter, or to all matter under peculiar circumstances.

Thus, every portion of matter may be divided; but some are hard to divide and others easy, as iron and water; and the difficulty or case of dividing these depends on their condition. When iron acquires much heat its parts are easily separated, and when water loses much heat its parts strongly cohere.

The general properties of matter claim our consideration first. These are, Impenetrability, Extension, Divisibility, Porosity Compressibility, Figure, Inertia, and Attraction.

A knowledge of the meaning of these terms will give us a much clearer idea of the manner in which everything around us exists, than we can possibly have without it. We will consider them in their order.

IMPENETRABILITY.

By this is meant that one portion of matter cannot penetrate another, or which is the same, occupy the same place which it occupies. Thus, though two houses or two spires may be side by side, they cannot both stand in the same place at the same time.

The same is true of objects in motion. When a train of cars passes along a rail-road, every portion of space through which the cars pass is occupied by each in succession, but the one in it must always leave before another can enter it.

These examples require no argument, but there are others which are not quite so clear.

When a nail is driven into a piece of wood, or when two liquids are mixed, they might seem to contradict this principle. But the nail only displaces the particles of wood, and does not enter them; and we cannot mix one liquid with another, without causing the two to occupy more space than one did.

To understand this clearly, we must remember that every substance is composed of atoms, or minute particles, every one of which must have a separate place, which no other atom can enter till the first one is removed.

EXTENSION.

We cannot conceive the existence of a body without attributing to it the quality of extension, or of having length, breadth, and thickness. We shall readily see this illustrated if we contemplate any building, as, for instance, the City Hall of New York.

But we must remember that in speaking of large objects placed on the ground, we generally call the thickness the height.

We can see that without dimensions in three directions the structure could not possibly exist. If we suppose it to have its present length and breadth, but to have no thickness, we destroy the idea of it, for if it were as thin as a sheet of paper, it would have some thickness.

We shall also fail if we try to imagine it to have height and length, but no breadth, or height and breadth, but no length.

This is true not only of large objects, but of the smallest that can have existence. We can thus see that the property is a universal one.

QUESTIONS.

What is composed of matter?
What two kinds of properties has matter?

What are the general properties of matter?

What is meant by Impenetrability?

When a nail is driven into wood, does it enter the particles of the wood?

Of what are all substances composed?

What is Extension?

What do we call the thickness of a large object placed on the ground?

In how many directions must a body have extension?

SECTION 2.

DIVISIBILITY.

If we again direct our attention to the City Hall, represented in the preceding section, and suppose it to be a solid body, we shall understand that it might be divided into two parts, so that each should be only half as large as the whole is. Each of these parts might again be divided, and thus we might proceed in dividing the parts till they became too small for us to hold them to make farther divisions. Yet if we could hold them, and had implements sharp enough, we could still go on dividing as before, and to this we can set no limit; for we have seen that every body must have dimensions, and there is no reason why these might not be less than they are, whether the body is large or small.

Yet, though the divisibility of matter is entirely consistent with our reason, there are many examples of it which astonish even those who are accustomed to consider the wonders revealed by science.

Gold leaf may be beaten into leaves of only the 282,000th part of an inch in thickness, and yet we know that, according to our previous conclusions, this thickness might be again and again divided. And we have a practical illustration of this, for we are told that if a piece of ivory, or white satin, be immersed in a nitro-muriate solution of gold, and then exposed to a current of hydrogen gas, it will become covered with a surface of gold hardly exceeding in thickness the ten-millionth part of an inch.

The soap-bubble is another instance of great divisibility. When we see their gaudy colors playing over them, they are not more than the 2,000,000th part of an inch in thickness, and the black spot which may be seen near the top just before they burst, has a thickness of only the 2,500,000th part of an inch.

But these examples, however surprising, are less wonderful than those which the microscope reveals to us in the animated world.

The little spot of mould which we may see on a withered leaf, and which seems to the unaided eye to be only a stain, is found, when strongly magnified, to be a complete forest, resembling in every respect, except their dimensions, those in whose shades we have sometimes wandered. The seed from which a tree will grow huge enough to form the mainmast of the largest ship, is a small grain. How small must then be the seeds from which grow the trees in the forest of mould, which, when full grown, seem to the eye to be nothing more that mere color.

Sapphire lenses for microscopes have been made which magnify the bulk of an object 1,000,000,000 times. This enables us to see objects 1,000,000,000 of which collected into a mass, would be barely visible to the unassisted eye. Yet each of these is made up of muscles, nerves, and other parts, like larger animals; for, like them, they are seen to have strength and activity. The globules which give color to our blood are too small to be distinguished without a microscope. How small then must be the globules which swim in the veins of those minute animals!

QUESTIONS.

What is Divisibility?

To what thickness may gold be reduced by beating it?

What is the thickness of soap-bubbles?

What are the spots of mould on withered leaves found to be?

To what extent have lenses been made to magnify an object?

SECTION 3.

POROSITY—COMPRESSIBILITY.

POROSITY.

When we observe a piece of spunge or pumice, we find that it is not solid, but so full of openings that, if the substance were pressed together closely, it would occupy much less space than it does otherwise. These openings are called Pores, and those substances in which they are very apparent are said to be porous. In light substances the pores are generally much more easily discovered than in those which are heavy; but they exist in every substance, including the finest and heaviest metals, and stones. We shall mention several facts which prove this.

Pieces of hard wood, marble, or granite, may be shown to be porous, and to contain a considerable quantity of air in their pores, by this simple experiment:—Put those substances in water, and place the water containing them under the receiver of an air-pump. Now, if the receiver is exhausted, and thus the pressure of the external air withdrawn, the air will issue from the pores of the wood or stone, and bubble up through the water. This proof will be convincing to those who have considered the nature of the air-pump.

If a tall vessel, having a wooden bottom, is filled with mercury, this substance will be forced through the pores of the bottom by its own weight, and fall from it in a fine shower.

Some substances are transparent; others semi-transparent, and the rest more or less opaque. Now this difference arises merely from their permitting light to pass through them more or less freely. It is very evident that if they were not porous, neither light nor anything else could pass through them.

There is another class of proofs. By the mass of a body is meant the amount of its substance; by the volume of a body is meant the amount of space which it occupies. If a body were perfectly solid, its mass and volume would necessarily be the same; but this is not the case in a single instance. The volume of every body can be reduced without diminishing its mass. Iron, and many other substances, may easily be reduced in volume by being hammered; and the volume of every substance is increased and decreased by heat and cold.

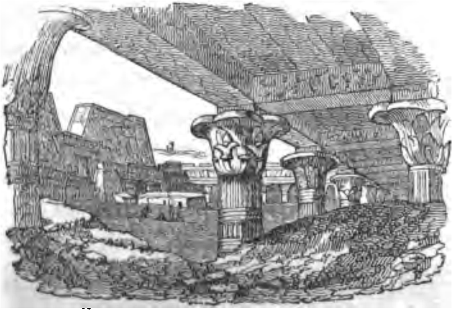
COMPRESSIBILITY.

After what has been said on porosity, no argument will be required to show that all substances are compressible, or capable of being diminished in volume, and that some are much more so than others.

We may easily show the compressibility of air by inverting a glass tumbler, or other vessel, and forcing it into water, with a burning taper or some other object floating on the water within the glass vessel. We shall see that the water rises in the vessel, and thus compresses the air.

Water was formerly supposed to be an exception, but it has also been proved to be compressible. At the depth of six thousand feet in the sea, the water is reduced, in volume, one twentieth by the pressure above it.

Marble and granite columns are frequently made to support a great weight. This we may see es-



pecially in structures built in the massive style of Egyptian architecture.

These substances could not be used for such purposes if they were not highly incompressible; but even they, when they bear a great weight, undergo some compression.

QUESTIONS.

What are Pores?

In what do pores exist?

How may pores be shown to exist in hard substances?

What is the difference between transparent and opaque bodies?

What is the difference between mass and volume?

Are the mass and volume of any body equal?

What is Compressibility?

What bodies are compressible?

How much is water compressed at the depth of 6000 feet?

Can very compressible substances be used for building?

SECTION 4.

FIGURE—INERTIA.

FIGURE.

We saw in a former section that a body must have extension, and we can readily understand that there must be a limit to its extension. This limit must exist on every side of the body, and therefore forms its Figure, by which is simply meant that property which is ordinarily expressed by the word shape.

There is no relation between figure and volume. The *vibrio undula*, an animalcule which is found in duck weed, is computed to be ten thousand million times smaller than a hemp seed. Yet these little beings have as definite a figure as an elephant or a world.

INERTIA.

Every body which we put in motion has, as long as it continues to move, to overcome the power of friction, the resistance of the air or other medium in which it moves, or other obstacles. It therefore requires great force to put a body in motion so that it shall move a long time unaided.

This naturally gives us the idea that matter has a tendency to rest, and so strong a hold does this supposition take on our minds, that not only the unreflecting, but even philosophers, in a period so recent as the seventeenth century, held it as a principle, that matter is more inclined to rest than to motion. This, however, is entirely incorrect. Matter cannot incline to motion or to rest in the least degree, because it is entirely devoid of will. When put in motion, it moves until it is stopped, and when stopped, it rests until it is again put in motion. It is therefore said to be inert, or to possess the property of Inertia.

This property is so important, that if we did not remember it we should fail at every step in our application of the laws of motion.

A consideration of the inertia of matter will explain many things which cannot be understood without reference to it.

A hare sometimes escapes a hound by turning, when almost overtaken, and running in the opposite direction. The hound wills to turn as soon as the hare; but his body being much larger, it requires a far greater effort to overcome its motion in one direction, and bring it to move in the contrary course.

Circus riders cause great astonishment by riding in such a way, that one unacquainted with the laws which govern moving bodies, would expect them to fall off the horses, and be left behind. But their bodies have been put into a motion as rapid as that of the horses, and it would require a strong obstacle to stop them suddenly. We see, therefore, that they move with their horses without an effort, and that they could not fall behind them, though they desired to do so.

If any object falls from the mast-head of a ship which is in rapid motion, it does not fall into the water behind the ship, but at the foot of the mast.

If we throw a stone from a carriage or railroad car, when moving with much speed, we must aim far behind the object which we wish to strike, or we cannot succeed.

All these cases are entirely consistent with the principle of inertia.

This principle also explains the fearful effects of collisions between bodies moving swiftly in opposite directions; as ships, steamboats, or railroad cars. Their tendency is to move on with undiminished speed, and it requires as much force to arrest their progress as would be necessary to give them their motion.

Without this principle a body would cease to move as soon as the power which put it in motion ceased to act. The cannon-ball, instead of moving with destructive force when it has travelled a mile or more, would only move while the exploding powder impelled it, and would therefore fall harmless at the cannon's mouth.

QUESTIONS.

What is Figure?

Have small objects figure as well as large ones?

What must a moving body overcome?

To what opinion does the force required to cause motion give rise?

Why can matter have no inclination to either motion or rest?

What is Inertia?

What is explained by inertia? What are several examples?

Without inertia, when would bodies lose their motion?

What effect would the loss of inertia have on a cannonball?

SECTION 5.

ATTRACTION.

Apart from a certain property inherent in bodies, and of which we should never think if we did not see the effects of it, there is no reason why a stone that is thrown into the air should ever return to the ground. The property which brings it down we call its weight, and this is possessed by every portion of matter, whatever be its form or position.

Some bodies, indeed, seem to contradict this, for they rise rather than fall. Such is the case of smoke, and various gases. They rise, however, not because they are devoid of weight, but because the air, in which we see them, is heavier than they. We see wood rise in the same manner in water, yet we do not suspect the wood has no weight.

The principle which confers on all matter this quality of weight, is called Attraction.

Notwithstanding the diversity which we observe in the weight of different bodies, attraction acts on all matter in a precisely equal degree at an equal distance. We must remember, however, that it does not act on the volume of an object, but on its mass.

The difference between the volume and the mass of a body constitutes its density. If its volume is large, compared with its mass, its density is small. If its volume is relatively small, its density is great. Thus, the volume of a piece of spunge or a feather is great, compared with its mass, and its density is therefore small; while the volume of gold is small, compared with its mass, and its density is therefore great.

Now, every body is heavy in proportion to its density; and this shows that it is the mass, and not the volume, that is attracted. This will become clear if we attend to the following statement of the principle which we are considering. Every particle of matter attracts every other particle of matter, without reference to the body in which it is contained. Thus, every particle of matter in a stone attracts the earth, and every particle of matter in the earth attracts the stone.

But since every particle attracts, many particles together will have much more power than a few. This explains the maxim, that attraction is in proportion to the mass, and shows us why the earth attracts a stone so much more than the stone attracts the earth. For if A and B are two bodies, A containing one thousand particles, and B one hundred, A will attract ten times as powerfully as B; and so of every other proportion.

The power of attraction decreases as the squares of the distances increase. Thus, at a certain distance from the earth's centre, say four thousand miles, which is about the distance from the centre to the surface, a particular piece of metal weighs one pound. At twice that distance the weight of the metal is only one fourth of a pound; at three times the distance, one ninth; and so on to any extent. For, 4 is the square of 2, and 9 of 3. At the distance of the moon, therefore, which is two hundred and forty thousand miles from the earth, that is, sixty times four thousand, the metal would weigh sixty times sixty less than on the earth, or one thirty-six-hundredth of a pound.

We see, in the world, constant illustrations of the action of this power. Every portion of matter, when not supported, moves towards the centre of the earth. The apple, when it ripens, and its stem grows weak, falls to the ground, and if it has grown on a hill-side, rolls into the valley. The rain falls from the clouds, and, in its tendency towards the earth's centre, flows to the lowest level which it can reach; and if, on its way, it comes to a precipice, it leaps from it, and strikes the ground below perpendicularly.

Nothing is able to resist this power permanently. The strongest fabrics erected by man, may stand during some hundreds or thousands of years, but then arch after arch, and column after column falls; and at length whole cities, which once seemed imperishable, have become desolate, and can only show a few ruins which are not yet prostrate. Of this, Palmyra, and many other ancient cities, are sad examples.

The earth itself does not escape the influence of attraction. Every stream that flows from the hills and mountains is constantly carrying clay and other matter down to the bottom of the ocean. The torrents, caused by rain, loosen large rocks, and precipitate them from cliff to cliff; and some of the principal rivers carry with them, annually, great numbers of the largest trees.

QUESTIONS.

What causes bodies to fall to the ground?

Why do some rise instead of falling?

What is the principle called which gives all bodies weight?

What is the density of a body?

In proportion to what is a body heavy?

What does this prove?

How may the principle of attraction be clearly stated?

Why does the earth attract a stone more than the stone attracts the earth?

At what rate is attraction decreased by distance?

How much would one of our pound weights weigh at the distance of the moon?

What are several illustrations of attraction?

What are some of its effects on the works of man and on the face of the earth?

CHAPTER II.

CONTINGENT PROPERTIES OF MATTER.

In the preceding chapter we considered those properties of matter which belong to it at all times and under all circumstances. But there are some which belong to some bodies and not to others, and some which a body possesses at one and not at another time. These are therefore called contingent properties. We will devote this chapter to the consideration of the most important of these.

They are, Cohesive Attraction and Capillary Attraction, Brittleness, Malleability, Ductility, Tenacity, Elasticity, Rigidity, and Flexibility.

SECTION 1.

COHESION—CAPILLARY ATTRACTION.

COHESIVE ATTRACTION, OR COHESION.

Of that attraction which draws all bodies towards each other, and thereby causes them to have the property of weight, we have already treated. The distinguishing name of this kind of attraction is Gravitation.

One of the chief qualities of gravitation is that it acts at all distances. But cohesion acts only at imperceptible distances. If we separate the particles of any substance sufficiently to see their separation, cohesion no longer acts on them.

As gravitation, by drawing bodies towards each other, gives them weight, so cohesion, by holding their particles together, gives them strength.

The degree of cohesion or strength in different bodies is exceedingly various, and all substances may, in regard to their cohesion, be divided into three classes: Solids, Fluids, and Gases.

In solids, the degree of cohesion is sufficient to enable us to form them into masses of different shapes. Such are clay, wood, stones, and nearly all the metals.

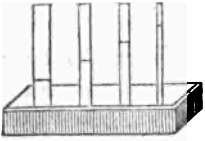
Fluids have so little cohesion that they will not from their own strength retain the forms which we give them, but will immediately adapt their form to the solids which compose their receptacles. Such are water, milk, blood, and the sap of vegetables.

Gases are not only deficient in cohesion, but their particles absolutely repel each other, so that when they are not secured, they generally escape and are dissipated; and, therefore, though there are many gases, the gaseous form is much less familiar to us than the other forms of matter.

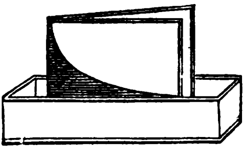
A substance may be at one time solid, at another fluid, and at another, gaseous. A good example of this may be seen in ice, water, and steam.

CAPILLARY ATTRACTION.

If a small glass tube is inserted in water, the water within it will rise higher than that on the outside: and the greater height of the inside column will be proportioned to the smallness of the diameter of the tube.



Thus, it will be seen in the annexed figure that in the tube of smallest diamemeter the water rises highest. The same can be illustrated by placing two pieces of glass together, so that two of their ends shall touch, and the other two be slightly separated. If we set them into a vessel in this manner, and pour a little water into it, the water will rise between the pieces of glass, and rise highest where the space between them is smallest.



This property of fluids, that they will rise in small tubes, we may easily see illustrated in a great variety of ways. If we place the lower end of a porous substance, as spunge, sugar, blotting-paper, or clay, into water, the water will be drawn up through it, and in a short time the whole will be wet. If we put the end of a towel into water in a basin, and let the rest of it hang over the side, it will draw all the water out of the basin. The pores in these substances are all really tubes, however short they may be. The rising of oil in the wick of a lamp, and sap in trees, depends on the same principle, as do also the motions of fluids in the pores of the bodies of animals.

QUESTIONS.

What properties of matter were considered in the preceding chapter?

What is another class?

What are they called?

Which of these are to be considered in this chapter?

What is the distinguishing name of that attraction which gives weight?

How does this differ from cohesion in extent of action?

What property does cohesion give bodies?

How may bodies be divided in regard to their cohesion?

What degree of cohesion have solids?

What degree have fluids?

Have gases cohesion?

Why are we not more familiar with matter in the form of gases?

May a body change from one of these conditions to another?

What is an example?

What experiments will show the existence of capillary attraction?

On what do the rising of oil in wicks, and sap in trees, depend?

What depends on the same principle in the bodies of animals?

SECTION 2.

BRITTLENESS—MALLEABILITY—DUCTILITY—TENACITY.

BRITTLENESS.

THOUGH cohesion is a property of all solids, it acts very differently in different substances. Some are soft, and yet have great strength. Such are for instance the hides of animals, of which we make leather; and some vegetable productions, as Indian rubber. Others have considerable hardness, and yet not much strength. These are called brittle; and as specimens of them we may mention chalk and glass.

MALLEABILITY.

Those substances which are remarkably brittle will not bear a considerable blow with a hammer without being fractured. But there are substances which we may beat into any shape and almost any degree of thinness without fracturing them, and they are therefore said to be in a high degree malleable.

This property belongs to the metals generally, but especially to gold. Of this we have a striking proof in the manufacture of gold-leaf. The goldbeater begins his operation by taking a riband of gold, which, by being passed through rollers, has been reduced to the eight-hundredth part of an inch in thickness. This riband he cuts into squares and puts between leaves of vellum, and they are thus beaten with a heavy hammer till they are ten times thinner than the riband was. The pieces are then again quartered, and, being placed between folds of goldbeaters' skin, are beaten with lighter hammers, till their thickness is but the 280,000th part of an inch. And they might be reduced still more without being fractured.

DUCTILITY.

Some substances are remarkably capable of being drawn out into wires, and they are therefore said to be Ductile. This is the case with many of the metals; and those are not always most ductile which are most malleable. Thus, though gold is the most malleable of metals, platinum is the most ductile. Wires have been made of this metal which were only the 30,000th part of an inch in thickness.

The ductility of many substances depends on their temperature. This is the case with wax and glue. Even glass, brittle as it is at its ordinary temperature, may so easily be drawn into threads when heated, that it has been introduced into the materials used for making ladies' dresses.

TENACITY.

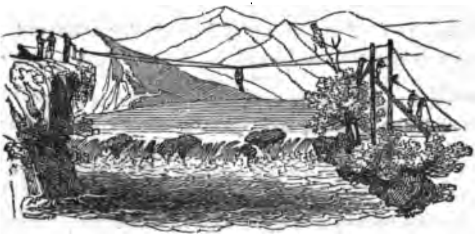
This term is used to express the degree of cohesion by which the particles of a substance are held together.

Tenacity is one of the most generally useful of all the qualities of matter. It is considerable in fibrous substances, as is shown by flax and hemp, which, when twisted into cords or ropes, cannot be broken without the application of great force.

But a rope made of iron wire is found to be one of the most tenacious of all forms of matter. Of this fact a most important application is made in the construction of what are called suspension bridges. A beautiful structure of this kind crosses the Schuylkill, at Philadelphia; but the most remarkable suspension bridge that has yet been erected, stretches over the Menai Strait, between Wales and the isle of Anglesea. It is one hundred feet above the level of high water, and the distance between the opposite piers is five hundred and sixty feet.

This principle for making bridges is by no means a new one. The American Indians, and other uncultivated nations, have employed it to some extent from time immemorial; and in some parts of South America it is used by the descendants of Europeans.

But there is a great difference between these primitive bridges, and those which modern science has enabled us to build, in the perfection of the structure, and the tenacity of the materials employed. The Indians made theirs of vegetable fibres, or thongs made of the hides of animals. The South American one, represented in the cut,



is made of ropes, and the passenger is drawn across in a basket suspended from the ropes. These, of course, are far less enduring and convenient than those made of iron wire.

These bridges, as might be supposed, are liable to a vibrating motion. The severest trial, therefore, to which the tenacity of their materials can be put, is to subject them to the effects of the measured tread of a long line of infantry.

QUESTIONS.

Why are glass and chalk said to be brittle ?

Why are some substances said to be malleable ?

To what class of substances does this property particularly belong ?

How is gold-leaf made ?

Why are some substances said to be ductile ?

Which is the most ductile ?

How thin have platinum wires been made ?

On what does the ductility of many bodies depend ?

What are examples ?

What is Tenacity ?

In what is it considerable ?

What is one of the most tenacious of all substances ?

How is this fact made useful ?

What are examples of wire bridges ?

What is the height and span of the Menai bridge ?

How is the principle of suspension bridges shown not to be new ?

What is the difference between the primitive suspension bridges and those which scientific men have built ?

To what motion are these bridges liable ?

What puts their tenacity to the severest test ?

SECTION 3.

ELASTICITY—RIGIDITY—FLEXIBILITY.

ELASTICITY.

All matter seems to be composed of atoms of inconceivable minuteness, which never come in actual contact, but remain suspended among each other by the opposite forces of attraction and repulsion. That they do not touch is proved by the compressibility of matter; for if the atoms touched each other, the bodies could no longer be compressed.

Now, when the particles are pressed together, their repulsion acts more and more strongly with every increase of the pressure; and when they are drawn apart, their cohesion acts as strongly to bring them together again.

This tendency of the particles to resume their positions when removed from them, is called Elasticity. It is strikingly exhibited in Indian rubber, while it can scarcely be perceived in clay. Most solid bodies possess it in some decree. In fluids there is very little of this quality, while in aeriform bodies it exists to a surprising extent.

RIGIDITY.

This is the resistance of a body to a change of form. It is the same as what is ordinarily called stiffness. This quality is of great importance in the construction of machinery; for that material will transmit power best which is most rigid, except in the case of the cord, which will be explained hereafter.

It does not follow, however, that the most rigid substance is most suitable for any particular purpose, because it may not have the requisite tenacity. It was mentioned that suspension bridges are liable to vibration. This is because the ropes of iron wire, which are used on account of tenacity, are deficient in rigidity. A substance which would unite these two qualities in a sufficient degree, if it could be procured in abundance, would soon take the place of iron wire in these structures.

FLEXIBILITY.

This is a quality opposed to rigidity and brittleness, and therefore means the quality of bending without a fracture. The metals, generally, are flexible, and are made more so by increase of temperature, except in the case of brass, which is made brittle by heat.

Animal and vegetable substances are made flexible by combination with liquids. This is illustrated by young plants and new twigs of trees. They are filled with sap, and are remarkably flexible. As they become dry, they lose this quality in a very great degree.

The flexibility of bodies increases as their thickness is reduced; and many thin bodies, if they are somewhat free to move among each other, are more easily bent together than one thick one. Thus, a rope of hemp is much more flexible than a hemp-stalk of equal thickness.

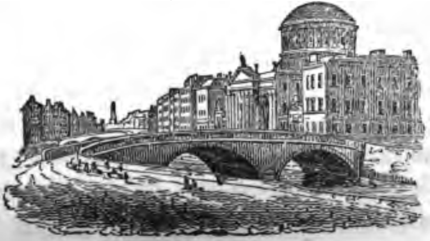
APPLICATION OF MATERIALS TO ARCHITECTURAL PURPOSES.

One of the most striking purposes to which materials are applied, is the building of dwellings, and of churches, bridges, and other public structures. It is of great importance to have these as convenient and durable as possible; and for making them so, it is necessary to be well acquainted with those properties of bodies of which we have been speaking.

The knowledge of them has always been important, but it becomes constantly more so as we improve in the art of building. Thus, to the builders of the Parthenon, at Athens, as they erected perpendicular walls and colums, and laid the upper materials horizontally on these, it was only ne-

cessary to be assured that their materials were rigid and inelastic.

But since the arch, which was invented not long before the Christian era, is extensively applied in constructing domes and bridges, and in various other ways, the architect must be well acquainted with the flexibility, tenacity, and other qualities of the materials which he employs. A specimen of the two applications of the arch which have been mentioned, may be seen in the view of the Four Law Courts, of Dublin.



From the ignorance of the builders in regard to the qualities of their materials, an edifice sometimes falls to the ground when it has scarcely been finished; and others become unsafe long before the time anticipated by those who erected them. The dome of St. Peter's Church, at Rome, which is one hundred and thirty-nine feet in diameter, and the most magnificent in the world, was intended to be very enduring; but it has already become necessary to put iron bands around to sustain it.

QUESTIONS.

Of what is all matter composed?

What proves that the atoms of matter do not touch?

How do repulsion and cohesion act?

What is Elasticity?

In what is the presence of this quality exhibited?

What is Rigidity?

Why is this property important in the construction of machinery?

Why are iron wires liable to a vibratory motion?

What is Flexibility?

What substances generally have this property?

What increases the flexibility of metals?

Which metal is an exception?

What increases the flexibility of animal and vegetable substances?

How is this illustrated?

What is one of the most important purposes to which materials are applied?

To make structures durable, with what must we be acquainted?

What properties of matter were chiefly important to the builders of the Parthenon?

Why were these most important?

To what is the arch applied?

Of what properties does its application require a knowledge?

What sometimes results when builders are not well acquainted with the properties of their materials?

What is an example of this?

CHAPTER III.

REST AND MOTION.

SECTION I.

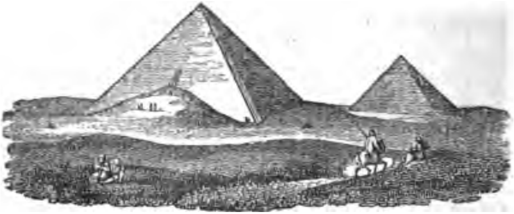
CENTRE OF GRAVITY.

We have seen that gravitation draws every particle of matter towards the centre of the earth. This may be illustrated by very soft putty or dough. If we make a pile of it, the upper part will press down till the whole is level and flat.

But most bodies are too rigid for this operation. Thus, if we set up a block of wood or marble, it will either stand or fall, but not settle down, like a soft substance.

The part of a body which stands on the ground or any other support, is called its base; and if more than half its weight is directly over the base, or balanced across it, the body will stand; while if it leans so that more than half its weight falls over either side of the base, it will fall to the side to which it leans.

From this it will be seen that a base which is broad in proportion to the height of the body, gives it great stability. This is illustrated by the geometrical figure called a pyramid; and it was therefore wise in those Egyptian kings who wished to build enduring monuments, to choose the pyramidal form.



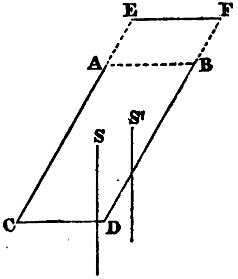
No storm could overturn these structures, and not even an earthquake, though it might be violent enough to rend them to pieces.

The erection of a pyramid evidently requires no great attention to the principles of gravity. But the case is very different when we wish to erect a tower or column. Thus, if the principles of gravity had not been observed in building the London Monument, which, with forty-two feet of base, is two hundred and two feet high, it would be very likely to fall; and with all the care of the architect, it has been thought to be in danger of such an event.

For convenience, only one point is considered

in calculating the stability of a body. That point is its centre in reference to its weight, and therefore called its Centre of Gravity. As long as that point is directly over any part of the base, the body will stand; but if it is not over the base, the body will fall. And on this account, a body which is low may lean more than a high one.

To illustrate this, suppose we set up the body A, B, C, D. The centre of gravity is at S, and as this is over the base, the body will stand. But if we add the part A B F E, the centre of gravity will rise, a line passing perpendicularly through that centre would pass outside of the base, and therefore the body would fall. The perpendicular line through the centre of gravity is called the Line of Direction.



The principles which we have been considering in reference to buildings and inorganic matter, are equally applicable to animated beings. Those animals which, like man and the feathered races, have but two feet, have a narrow base; and as they must balance themselves on this, they learn, with difficulty, to walk. This may easily be seen by observing the pheasant, in the cut.

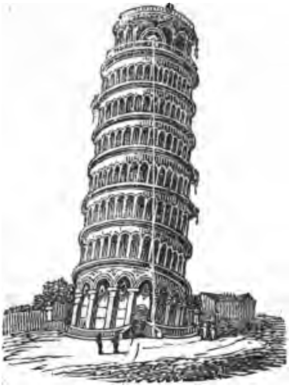
Quadrupeds, on the other hand, like the pyramid, have a broad base, and hence learn to walk early, and, after acquiring some strength, are always secure on their feet. The horse is an example of this; and, from this cause, a skilful rider is less liable to fall while mounted than when on foot; for though he is higher, the extent of the base made

by the feet of the horse is more than proportioned to the height of the rider.

When a man carries a weight in his arms, he leans backwards; when he has a load on his back, he leans forwards; and when a burden is on his head, he stands erect. This he is compelled to do to keep his centre of gravity over his feet.

The art of the rope-dancer consists in his power to keep his centre of gravity over the narrow base on which he stands; and on the ease with which this is done, depends mainly the gracefulness of dancing.

An accurate observation of the centre of gravity, and its line of direction, would sometimes prevent the fears which we entertain, that a wall or tower is in danger of falling, while, in reality,



it stands firm. Thus, on approaching the Leaning Tower, at Pisa, in Italy, the casual observer might fear that it would crush him. But if we observe the white line on it, which is its line of direction, we shall see that it falls far within the base. The tower is one hundred and thirty feet high, and leans nearly sixteen feet; but this is much less than half its diameter. It is not known whether the ground has partially given way under it, or whether the architect built it so as a curiosity; but it has stood in this position during several hundred years, and is likely to stand much longer.

QUESTIONS.

Towards what point does gravitation draw every particle of matter?

How may this be illustrated?

Why do solids not become flat from gravitation?

What part of a body is called its base?

When will a body keep its standing position?

What results if the chief weight of a body is on either side of the base?

What gives a body stability?

By what figure is this shown?

What structures are a practical illustration of this?

What are the dimensions of the London Monument?

To what principles was it necessary to attend in its erection?

What is the Centre of Gravity?

Why may a body that is low lean more than a high one?

What is a perpendicular line passing through the centre of gravity called?

What animals have a narrow base?

What animals have a broad base?

What advantage does this give them?

How, under the different circumstances mentioned, does a man keep his centre of gravity?

On what depends the art of the rope-dancer?

Of what advantage does it sometimes prove to observe the centre of gravity and line of direction?

What tower is an example of this?

SECTION 2.

MOTION.

Every one has observed, that when a ball is struck with the hand or a paddle, it moves in the direction in which it is struck, and with a velocity proportioned to the blow. A careful consideration of this fact will give us a foundation for our philosophy of Motion.

If the ball is struck by a paddle, the paddle must have had a certain degree of motion. Without this it would not itself have moved. This motion was given it by the effort of the arm and hand of the person who held it. We know, from the principles of inertia, that if the ball is at rest, it will remain so till some force puts it in motion; and that when in motion, it will move on until it is stopped by some obstacle.

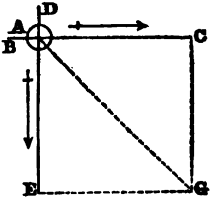
This is equally the case with the paddle; and, since this is put in motion by the person striking, its tendency is to move on indefinitely. But as soon as it strikes the ball, it loses this tendency. What is the cause of this? Simply that the motion which the paddle had has now passed out of the paddle into the ball, and therefore it now has the tendency to move on.

It is true, that we cannot see motion except as an effect on bodies; nor can we confine it in a vessel, as we may air or hydrogen gas. But we can measure it with the utmost precision, and pass it out of one body into another, so that there shall be none whatever left in the first body; or we may equally divide it among two or more bodies.

We mentioned that the ball would move in the direction in which it is struck. Now, suppose it were struck by two paddles with equal force, the one paddle moving east and the other north, in which of the two directions would the ball move? Evidently in neither, but in a direction between the two, equally distant from each; that is towards the northeast. And if either of the paddles alone would have driven it ten feet in a second of time, the two together would drive it over the diagonal of a square of ten feet on each side.

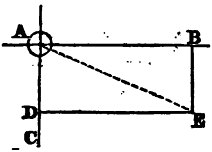
This may not be very clear to beginners, but it may be made plain by the annexed figure:

Suppose A to be the ball, and that one paddle strikes it in the direction of B C, and the other in the direction of D E; it will then, instead of moving to C or E, move across the square to G.



This is what is called the Resolution of forces, or resolving forces into their elements; and it will hold in every case in which motion is communicated by a blow.

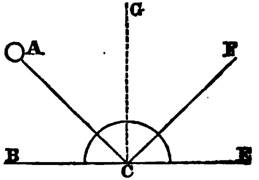
Let us make another application of the principles laid down. If one paddle strikes only half as hard as the other, as is represented in this figure, then the ball will not take a direction equally distant from them, but will move most in the direction of the one which strikes it hardest.



This can only be illustrated when the ball receives what is called a fair blow. It moves in the direction in which it is struck, and, therefore, if it is struck on one side, it moves to the opposite side. This almost always occurs when one round body strikes another. Thus, if one marble strikes another, they move in directions which are determined by the manner in which they strike each other.

If one marble strikes another only half its own size, they will both move on, but the small one will move twice as fast as the large one, because the large one, before they struck, contained twice as much motion as the small one would contain, if moving at an equal rate. For the motion of a body is as its own mass and velocity. That is, if a body weighs one pound and moves at the rate of ten feet in a second, it has sixteen times as much motion as if it weighed only an ounce; and ten times as much as if, weighing a pound, it moved only one foot in a second.

When a moving body strikes another which is much larger, or which is prevented from moving by some obstacle, it rebounds or is reflected; and this occurs according to the following principle: The angle of reflection and the angle of incidence are equal. The meaning of this expression is this: that moving towards the surface which it strikes at a certain angle, it rebounds at the same angle. Thus, let A in the figure be a ball moving towards a smooth surface at C, when it has struck it will rise in the direction of F, which forms the same angle with C E, that A forms with C B. If the ball had come in the direction of G C, it would move back in the same direction.



QUESTIONS.

How is a ball affected by a blow from a hand or a paddle?

What must a paddle have before a ball may be struck by it?

What does inertia teach us in regard to the motion of the ball?

Why does the striking paddle lose its tendency to move?

Though we cannot see motion, what may we do in regard to it?

If a ball is struck by two paddles at the same moment, what is the result?

What is the Resolution of forces?

If a large ball strikes a small one, what is the result?

What is meant when we say the motion of a body is proportionate to its mass and velocity?

When a body strikes another larger than itself, what occurs?

What principle holds in regard to reflection?

What is the meaning of this?

SECTION 3.

FALLING BODIES.

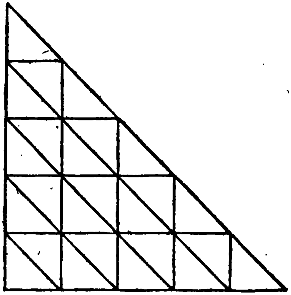
GRAVITATION, it will be remembered, is constantly drawing every object towards the centre of the earth. Now, suppose that a stone is dropped from a high tower. In the first second of time gravitation would draw it down through a certain space. Experiment proves that this space would be sixteen feet one inch. But for simplicity we will suppose it to be sixteen feet without a fraction.

As gravitation gave it a motion of sixteen feet in the first second, it would give it sixteen more in the next second; for it acts on moving bodies as well as on those which are stationary. The second quantity of motion, therefore, does not take the place of the first, but must be added to it.

At the commencement of the first second the stone just began to move, and not having acquired much motion, it could not exert much. It therefore moved very slowly. But in every interval of time its motion was doubled; so that, at the end of the second, it had moved through sixteen feet.

Now, as at first its motion was really nothing, it must, to average the rate of sixteen feet through the second, have been moving at the rate of twice sixteen feet at the end of the second. So that, if it moved on uniformly through the next second just as it was moving at the end of the first, it would fall through twice sixteen, or thirty-two feet. But we must add the sixteen feet which gravitation produces in each second. It therefore moves through three times sixteen feet in the second second.

We have seen that in the first second it moves through one space of sixteen feet, in the next second through the one space of sixteen feet, and two additional ones; that is, that two such spaces were added. Now, precisely the same increase which took place in the second second, would take place in the third and every additional one. It therefore in the third second moves through five such spaces; in the fourth, through seven; and so onward, according to the odd numbers.



This may be illustrated by the annexed figure. In the first second the velocity of the stone may be represented by the single triangle at the top of the figure. The three triangles next below it will represent the velocity of the stone in the next second. The next row will represent its velocity in the third second, and so on. This increase of velocity is called Acceleration.

If we wish to find what is the velocity of the falling body in any second of its fall, we must multiply sixteen feet by the odd number corresponding with that second. Thus, to find through what space it would move in the fifth second, we must multiply sixteen feet by nine, which is the fifth odd number. This will give 144 feet.

But to find how far it has fallen in any number of seconds, we must multiply sixteen by the square of the seconds. For instance, we may wish to know how far a stone has fallen in four seconds. Now, the square of a number is the product of the number multiplied by itself. Therefore we must multiply sixteen by four times four, or sixteen, which gives us 256.

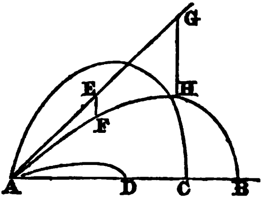
We may sometimes find this rule convenient when we wish to measure the height of any object, and do not care for great accuracy. Suppose, for instance, that a traveller is desirous to know the height of the Indian tower at Delhi, which is re-

presented in the cut. When he arrives at the top he takes out his watch, and dropping a stone from his hand, observes how long it occupies in reaching the ground. If the time is rather less than four seconds, he will err very little in judging the height of the tower, which is 242 feet.

This measure may be used not only for a tower, but for a building of any form, and even for a broad sloping hill; for it will answer equally well, whether the ball is dropped perpendicularly down, or projected forward; since gravitation acts with as much power on a body which is moving forward in the air, as on one which is falling without a forward motion.

To illustrate this, suppose a cannon to be placed on a wall sixteen feet high. If a ball were to drop from its mouth, it would reach the ground in one second. But instead of this it is thrown forward by the force of exploding gunpowder, at the rate of a thousand feet in a second. It will then, while it is moving forward one thousand feet, fall sixteen, and reach the ground at the end of the first second.

On this account, when a ball is to be thrown far, it is necessary to point the cannon considerably upwards. This may be seen in the figure. If we wish to throw a ball from A to B, we must direct it towards G. Now, if free from the influence



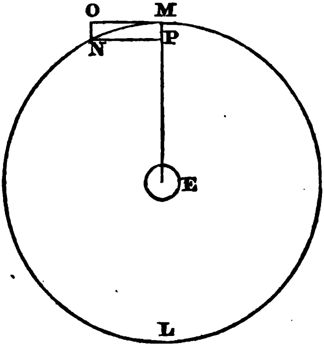
of gravity, it would, in one second, have reached E. But instead thereof, it reaches F in the first second, sixteen and one-twelfth feet below E, or just as far below it as it would have fallen in that time if dropped from E. So, at the end of two seconds, it will be, not at G, but at H, sixty-four and one-third feet below G.

This shows, that a body moving freely in the air obeys the same law of descent, whatever may be the direction in which it is thrown. We may easily verify the principle by taking two marbles, and projecting one from the surface of a table at the same instant at which we drop the other from the table's edge. If the experiment is fairly tried, they will strike the floor at the same moment.

It is found that a ball will go farthest from a cannon which is elevated to an angle of about forty-five degrees, or half-way between the horizon and the zenith. If it were directed much higher than this, as represented by the upper line in the figure, the ball would strike at C; and if directed much too low, as represented in the lower line, it would strike at D.

When we consider that not only these facts, but also the resistance of the air, the length of the cannon, the amount of powder used, and other circumstances must be taken into account by the gunner, when he is aiming his piece, we find that his destructive art is one of much intricacy, and requiring great skill.

The most beautiful illustration which we have of the law of falling bodies, is presented by the heavenly bodies moving round each other in their orbits.



Suppose E, in the figure, to represent the earth, and M the place of the moon. In a certain time it would move from M to O. But it is, meanwhile, falling towards the earth as far as from M to P. Its forward and falling motions together, therefore, carry it in the given time to N, and thus it proceeds through its whole orbit.

QUESTIONS.

How far does a falling body move in a second?

What is the result of its motion in the next second?

At what rate does it move at the end of the first second of time?

How far then does it move in the next second?

What is the rate of increase of the motion of falling bodies?

What is this increase of velocity called?

How do we find its velocity in any given second?

How do we find how far it has fallen in a given number of seconds?

What application may we make of this rule?

In what cases may this measure be used?

Why may it be employed for almost any elevation?

How is this illustrated?

How then must a cannon be directed to throw the ball far?

What do we discover in regard to bodies moving in the air?

How may this easily be shown?

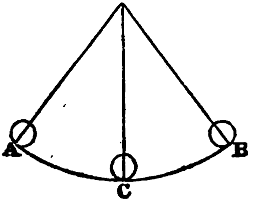
How must a cannon be directed to throw farthest?

What is the finest illustration of acceleration?

SECTION 4.

THE PENDULUM.

We have seen that a body, when falling, acquires velocity at a certain rate of increase, and that this takes place whether it is falling perpendicularly or moving forwards while falling. The same law will hold when the body, instead of falling unsupported through the air, is suspended by a cord or any other substance.



Thus, suppose the annexed cut to represent a ball suspended by a rod. If we move it from C to A, we raise it some distance higher than it was, say three inches; and if we then let it move freely back to C, it will acquire the velocity which it would acquire in falling three inches, and this will be sufficient to carry it on to B. It will then fall back to C, and rise to A; and this motion, were there no friction at the point of suspension and no resistance from the air, would continue the same as long as the materials would hold together. Such a body is called a Pendulum.

An arc of a small circle is more curved than an arc of a large one, as any one may see by drawing circles or arcs of circles of different sizes on a slate. The ball of a pendulum describes an arc of a circle in its motions, and the centre of the circle is at the point of suspension, and the size of the circle depends on the length of the pendulum. If the pendulum is short, therefore, the fall of the ball is steeper than if the pendulum is long, and consequently it will fall faster. This explains why those planets which are near the sun, move faster in their orbits than those which are distant from it.

The motion of the pendulum from A to B is called an Oscillation or Vibration.

The vibrations of a pendulum, while its length is unchanged, are equal in duration. If it makes one vibration in a second, the next will be made in a second also, and so will the third, and any number more.

This property of the pendulum led to the idea of employing it as a measure of time; and, accordingly, about two centuries ago, it was applied to the construction of clocks. It is not agreed whether it was Huygens or Galileo who made this useful invention.

The greatest obstacle in the way of making clocks that will keep time regularly, is the impossibility of making pendulums that will not vary in length. For every substance yet discovered will expand and contract when exposed to changes of temperature. The pendulum is therefore longer, and its motion slower, in summer than in winter. Various means have been adopted to overcome this difficulty, but none with entire success.

The motions of the pendulum depend entirely on gravity. If we could remove this power from it, it would no longer vibrate. If we decrease the influence of gravity over it, its vibrations will be slower; and this we may do, by taking it to the top of a mountain; for as we recede from the centre of the earth, its gravitation decreases. This shows that the pendulum of a clock adjusted for a plain or valley, must be shortened to keep good time on a mountain.

The earth is flattened at the poles. Its diameter at the equator is about 28 miles more than at the poles. This fact was ascertained from the circumstance that the pendulum of a clock was observed to make one hundred and forty less vibrations in a day at Cayenne, in Guiana, than at Paris.

Taking a clock from either pole to the equator, beside the influence of increased heat, would have the same effect on it, as taking it to the top of a mountain fourteen miles in height. The length of the pendulum for measuring seconds must be adjusted to every degree of latitude; and its variations in the different latitudes enable us to ascertain the figure of the earth with great accuracy.

QUESTIONS.

In what case beside those mentioned does the law of acceleration prevail?

What is a body, suspended at one point and free to move at another, called?

Why does a short pendulum move quicker than a long one?

What are the movements of a pendulum called?

What is the relative time of different vibrations?

To what invention did the equality of the vibrations of a pendulum lead?

When and by whom was the clock invented?

What is the chief obstacle in the way of making clocks that will keep time regularly?

What is the cause of variations in the lengths of pendulums?

What is the cause of the motions of the pendulum?

How would the decrease of gravity affect it?

How may a decrease of gravity be effected?

How must the pendulum of a clock be changed if taken to a high mountain?

What is the shape of the earth?

How much greater is its equatorial diameter than its polar?

How was this ascertained?

How would taking a clock from the pole to the equator affect it?

SECTION 5.

FRICTION.

One of the most important properties of bodies in regard to machinery is Friction, or the rubbing of their surfaces. There is no instance of motion of one body along the surface of another without friction, and in many cases it is so great as seriously to incommode mechanical operations.

We have an example of this in the great force required to drag heavy objects, as wood or stones, along the ground; and we know that the difficulty of dragging them arises only from their friction, from the fact that if we lessen their friction, they move more easily. Thus, a sleigh is easily drawn on snow, and a stone will slide without great resistance on a smooth board, because snow and a smooth board cause less friction than the ground.

When a ship is launched it is made to slide into the water on beams which form what are called the ways; and these ways are greased, that the friction of the timbers may not prevent the sliding of the ship.

There are two kinds of friction: that produced by one body sliding over another, and that which arises from the rolling of one body over another. The latter is far less powerful than the former, and therefore a stone or other object of great weight is frequently put on rollers to be removed, instead of being drawn along the ground.

We found, in considering the property called inertia, that when a body is once put into motion, it would move for ever if it did not meet with obstructions. The most universal of these obstructions is friction. If we put a carriage in motion on a level and then withdraw the force which started it, its speed will decrease from the first moment of its being free from the impelling force, and in a short time it will stop.

A sleigh, especially without snow to move on, would stop much sooner than the carriage, which, being placed on wheels, meets with much less resistance from friction. The rim of the wheel is but little resisted, because it rolls on the ground; and the axle, which slides in the nave, is greased, that it may move with greater freedom than if it rubbed directly on wood or metal.

In some cases the friction of a machine is not great enough to stop it so soon as is desirable after the impelling power is removed. Thus, a railroad train, from the great speed with which it moves, will run a long time after the steam has ceased to impel it. To obviate the inconvenience which would result from this, a cross-beam, called a brake, is made to rub against the wheels, so as to produce the requisite friction. The same instrument is used to check the speed of wagons when descending hills.

It is not easy to imagine how different the world would be if all bodies lost their friction. The stones and all other loose objects would roll or slide from the hills and mountains, and go down the valleys till they arrived at the lowest places which they could reach, as water does now. And the brooks and rivers, instead of flowing gracefully along, would rush down the valleys and over the plains with the most frightful and destructive rapidity.

The mocking-bird, in the cut, sits securely on an almost perpendicular branch of a tree, on account of the great friction between its feet and the wood; and if this did not exist, it could not sit in such a position for a moment. The nails which, when driven into wood, are so firmly held, would fly from their places as we sometimes see smooth wedges fly out of a log. The furniture in our rooms, and the plates and saucers on the table, would not remain where we placed them, unless the table and the floors were perfectly level. The stones and clay of the streets would be more slippery than the smoothest ice, and to walk up a hill would be impossible.

QUESTIONS.

What is Friction?

Between what bodies does friction occur?

What examples have we of friction?

What proofs are there that these are effects of friction?

What remarkable example is there of artificial diminution of friction?

What two kinds of friction are there?

Which is the more powerful?

How is advantage taken of this fact?

What is the most universal obstruction to friction?

What is a consequence of this?

Why would a sleigh stop sooner than a carriage?

In what case is the friction insufficient?

How is this want supplied?

In what case is the brake used?

What would be the result if all bodies lost their friction?

CHAPTER IV.

THE MECHANICAL POWERS.

SECTION 1.

MACHINES.

THE principal part of the time of a great portion of the human family is devoted to labor, for the production of the necessaries, comforts, and luxuries of life. Any invention, therefore, which tends to lessen the time of labor, or to increase its productiveness, may be of vast importance, especially as that invention which is beneficial to one man in the performance of his labor, may be equally useful to the millions of others whose work is similar.

There are numerous contrivances used to facilitate the operations of the laborer, and they are all called by the general name of Machines. There are two kinds of these in use; those which operate merely on Mechanical principles, and those which derive their power from the application of Chemical principles. We will consider only the first class in this chapter.

A machine is either simple or compound. Simple machines are the elements of which the compound are composed. They appear in six different forms, which are called the Lever, the Wheel and Axle, the Pulley, the Inclined Plane, the Wedge, and the Screw. These are called the Mechanical Powers.

We should be careful not to adopt the mistaken idea which is entertained by many, that by these machines we can produce power. They are only the means by which we advantageously apply it. The principle will hold invariably in the use of these machines, that what is gained in power is lost in time. Thus, a machine which will raise a ton may be made powerful enough to raise ten tons: but its operation will then be ten times slower.

And not only so, but from the friction of the materials, and the resistance of the air, there is a loss of power, and this loss increases as the machine is made more complicated.

The discovery of Perpetual Motion has long been a celebrated problem in mechanics. Thousands of persons have endeavored to make the discovery at a great expenditure of time and money. Had they understood clearly that machines never generate power, and that more power is required to put them into operation than they exert, they would have known that perpetual motion is a phantom, and that the pursuit of it must end in disappointment, and perhaps the vexation of seeing afterwards that they had attempted to apply principles without studying them.

The advantage of machines may be illustrated in this way. Suppose that in erecting an edifice, a stone weighing two tons is to be raised from the ground to its place on the wall. Thirty men could perhaps lift it to the desired height in one minute with their hands. But there is only one man present. He must therefore lift it with a machine, which he can do; but what the thirty could do in one minute, he cannot do in less than thirty. Machines, then, enable one man to do the work, which without them, would require many.

But farther, the wall on which the stone is to be placed may be fifty feet high. It would be very difficult for thirty men to stand on the wall in a proper position to draw the stone up; and below they could not lift it more than six or seven feet. But the machine can be made to place the stone just where it is wanted. We thus see that machines not only enable us to exchange time for power, but to apply that power advantageously.

QUESTIONS.

To what is the chief part of the time of most men devoted?

What gives a useful invention its principal importance?

What are the contrivances for assisting in the performance of labor generally called?

Of what two kinds are machines?

Which of them are considered in this chapter?

What two kinds of machines are there?

Of what are compound machines composed?

How many simple machines are there?

What are they called?

Can machines produce power?

How are they then useful?

What principle is true in regard to machines?

How is this illustrated?

What else must be regarded in respect to the amount of power?

What has long been a problem in mechanics?

Is perpetual motion possible?

What proves that it is impossible?

What should we do in regard to principles before we try to apply them?

How may the use of machines be illustrated?

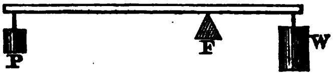
In what two ways are they useful?

SECTION 2.

THE LEVER.

THIS is the most simple of all machines. It consists of a bar resting on an axis, and having a weight acting on one part of it, and a power on another. The axis or support on which the lever rests, is called the Fulcrum. The weight is frequently called the Resistance.

There are three varieties of the lever, distinguished by the relative places of the power, fulcrum, and resistance. In the first, which is represented in the cut, the fulcrum is between the power and the weight.

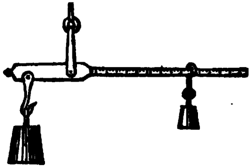


The principle of the lever is easily understood. If the fulcrum is in the middle of the bar, a power of one pound will just balance a weight of one pound. This is exemplified in the common balance, or scales, in which a pound weight at one end balances at the other end a pound of butter, or whatever else we wish to weigh.

But suppose the power to be three times farther from the fulcrum than the weight is; then it must be three times smaller than the weight: and if it is six times farther from the fulcrum than the weight, it must be six times smaller; and so of any other proportion. For the comparative effect of the power and the weight is always determined by their comparative distance from the fulcrum.

A seesaw, as the children call it, is an example of this. If the children who are seated on the ends are equally heavy, the fulcrum must be under the centre of the board. But if one of them is much heavier than the other, he must be much nearer the fulcrum. The distance in this case, however, is not precisely in proportion to the weight, because the weight of the lever itself, that is, the board, is considerable, and must be taken into account. The weight of the lever has, indeed, always some influence on the result of its own operation; but this influence is generally so small that it is convenient to disregard it.

The crowbar is a lever of this kind. The strength exerted by the laborer is the power; the stone which he is lifting, the weight; and the object on which the crowbar moves, the fulcrum. The spade used in digging the ground; the poker with which a coal-fire is stirred; and the handle of a pump, are familiar examples of this kind of lever.

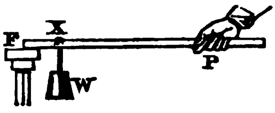


The steelyard is also a lever of this kind. The place of the fulcrum and the weight are immoveable. Now, as the weight varies and the power does not, it is necessary to have some compensation on the side of the power. This is obtained by having the power moveable. When the weight is small, the power is brought near the fulcrum; and removed far from it when the weight is large.

It was mentioned, that whatever is gained by machines in power is lost in time. This will be understood if we attend to the relative spaces through which the weight and the power move. If they are at equal distances from the fulcrum, they will rise and fall through equal spaces. If the power is three times as far from the fulcrum, it will move through a space three times as great as that through which the weight passes. If it were relatively to the weight a hundred times more distant, it would move through a hundred times more space.

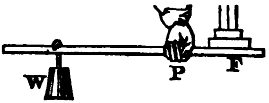
Archimedes, a most celebrated mathematician and mechanician, who lived in the third century before the Christian era, said, "Give me a lever long enough, and a prop strong enough, and with
is my own weight I will move the world." This
we contains a mathematical truth, though a practical
other impossibility. For if he could have obtained the
the pow [illegible] fulcrum, he must have moved mil-
by their c

lions of years with the velocity of a cannon-ball, to move the earth a finger's breadth.



The second kind of lever has the fulcrum at one end, the power at the other, and the weight between them.

Of this kind are nut-crackers, and a door moving on its hinges. The wheelbarrow is also a lever of this kind, the wheel forming the fulcrum, and the power being applied at the handles. A barrow on which two men carry a weight, is also an example. One or the other bears more of the load as it is moved nearer to him, because the other has then the advantage of a longer lever. The oar of a boat and the rudder of a ship also belong to this class; the water forming the fulcrum, and the boat or ship the weight.



In a lever of the third kind, the fulcrum is at one end, the weight at the other, and the power is applied between them. The peculiar feature of this lever is, that it acts at a mechanical disadvantage. For, as the weight is farther from the fulcrum than the power, the power must be greater than the weight. This is illustrated in the shears used for shearing sheep, and in the common fire-tongs.

The animal economy presents numerous examples of this class of levers. In the human arm, for instance, the socket of the bone is the fulcrum, the muscle attached to the bone the power, and the arm, with whatever we may be lifting, the weight.

It may seem strange that the lever chosen to hold so important a place should be one that acts at a mechanical disadvantage. But what is lost in power, is of course gained in time, which in this case is of much more importance. It is also the only one that could have been applied to the purposes of animal motion without producing great deformity. It is certainly better for us to be able to move gracefully and briskly, than to have the power to carry a thousand pounds, but only at a slow rate.

QUESTIONS.

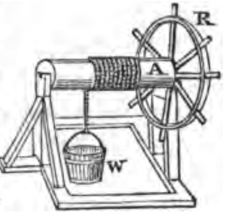
What is a Lever?
How many varieties are there?
How are they distinguished?
Where is the fulcrum in the first?
What is the principle of the lever?
What is an example of this?
How is the relation of the power and weight determined?
How do children balance each other on a seesaw?
Why is the weight of the lever generally disregarded?

How is a crowbar explained?
What other levers are mentioned?
How is the steelyard explained?
What is the relation of the power and the time?
What remark did Archimedes make?
What is the truth of this?
What is the character of the second kind of lever?
What are examples of this kind of lever?
What distinguishes the third kind of lever?
What are examples?
Why does it seem the most appropriate for the motions of animated beings?

SECTION 3.

THE WHEEL AND AXLE.

When the lever is clearly comprehended, there is no difficulty in understanding the Wheel and Axle, which may be said to be but a modification of it. For in this machine the radius, or semidiameter, of the wheel is equivalent to the long and the radius of the axle to the short arm of a lever, the pivots or gudgeons on which they rest, representing the fulcrum.

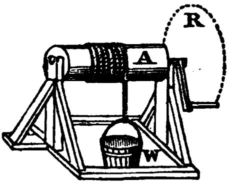


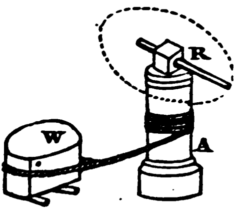
This may be understood by attention to the annexed figure, in which R is the wheel, A the axle, and W the weight. It will easily be seen that if the axle had as great a diameter as the wheel, there would be no gain of power, and that if it were larger there would be power lost; and that, on the other hand, the larger the wheel and the smaller the diameter of the axle, the greater will be the power gained.

We find here another illustration of the invariable principle, that what is gained in power is lost in time. Suppose that the well from which the bucket is to be drawn is 100 feet deep, and that the wheel is 20 feet in circumference. If the rope were wound directly on the wheel, it would only be necessary to turn the wheel 5 times round to bring the bucket up; 5 times 20 being 100. But if, instead of this, the rope is wound on an axle only 1 foot in circumference, the wheel must be turned 100 times to draw up the bucket. A man who could, in the first case, draw up 200 pounds in one minute, could now draw up 20 times 200, or 4000 pounds, but the operation would require 20 minutes; showing that he draws up just as much in one case as in the other, namely, 200 pounds in a minute.

The greatest advantage of the wheel and axle over the common lever, is, that it may be made to operate continuously. In using a crowbar, or other simple lever, we place it and move it to a certain distance; for instance, till it reaches the ground. We then repeat the operation, and this constant replacing of the lever causes a great loss of time. But with the wheel and axle we may continue to operate in one direction for any length of time, as is shown by the motion of a water-wheel, which moves the machinery of a mill. The wheel continues to move in one direction as long as the water, which is the power, operates on it.

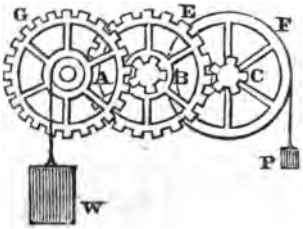
We may have all the advantages of the wheel and axle without actually having a wheel attached to the axle. The wheel may be called a circle of levers, but we have the advantages of the principle if we apply but one lever. This is shown in the windlass, as represented in the figure, in which the hand, or other power, applied to the crank, makes it revolve in the circle R. It evidently has all the advantages of a wheel, beside the additional one of being more easily constructed, and occupying less space when not employed. The grindstone, coffee-mill, and hand-organ, present examples of this construction.





The capstan is an application of the wheel and axle, differing somewhat from those which we have given. It is used on ships for hoisting the anchor and other heavy objects. Where space is so valuable as it must be on the deck of a ship at sea, a wheel, or even a permanent crank, would be inconvenient. A moveable lever is therefore used, and it again has the effect of a wheel; and when several levers are used for turning one capstan, even the form of the wheel is approximated.

Sometimes a number of wheels and axles are combined, so as to produce any kind of motion that may be desired. This is finely illustrated in the clock and the watch. The small wheels on



the end of the axles are called pinions, and their teeth are called leaves. Now, by proportioning the leaves of the pinions and the teeth of the wheels to each other, any relative speed may be given to them. Thus, of three wheels, suppose the last is desired to turn 60 times while the first makes 1 revolution. If the pinion of the second wheel has 5 leaves, and the first wheel has 60 teeth, the second wheel will turn 12 times while the first turns once; the product of 60 divided by 5 being 12. If the second wheel also has 60 teeth, then the pinion of the third wheel must have 12 leaves. Each revolution of the first wheel will then produce 12 of the second, and each of these 12 will produce 5 of the last; and, 12 times 5 being 60, the last wheel will make 60 revolutions while the first makes 1. This is the principle on which the hands of a time-piece are made to indicate the seconds, minutes, and hours.

It is frequently desirable to convey motion from a wheel at one place to another at some distance. For this a series of wheels might be used, but they would be expensive, and considerable power would be required to overcome the friction which would oppose their motion. The object is, therefore, effected by the use of bands. These are generally made of leather, and they connect the two wheels by being drawn over them. The efficiency of bands depends on friction, and as this is increased by tightening the bands, the only limit to its amount is the degree of strength of the materials employed.

QUESTIONS.

Of what is the Wheel and Axle a modification?

How is this machine explained?

How may the relation of power and time be stated?

What is the chief advantage of the wheel and axle over the common lever?

How may we apply the principle of this power without having a wheel?

What are examples?

What is a capstan?

What is an example of the combination of a number of wheels and axles?

How may any relative speed be given to such machines?

How may this be explained in the case of a clock or watch?

How may motion be conveyed from one wheel to another, when they are at some distance from each other?

On what does the efficiency of bands depend?

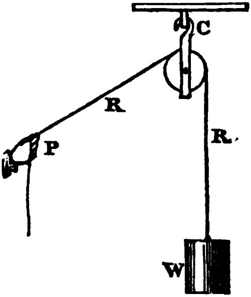
By what is the increase of the friction limited?

SECTION 4.

THE PULLEY.

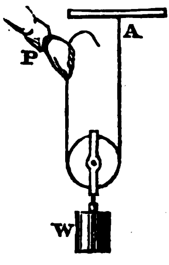
The pulley, in its simplest form, consists of a wheel called a sheave, a block within which the wheel moves on pivots, and a cord passing over the wheel in a groove on its edge.

A single pulley can scarcely be called a mechanical power, because no power can be gained by it at the expense of time. Thus, in the annexed figure, C is the pulley, W the weight, and P the power. Now, to raise the weight 1 foot, the cord must be drawn down 1 foot at P. A man could therefore raise no more by means of this contrivance, than he could raise directly from the ground with his hands.



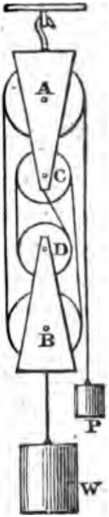
The single pulley is of great use, however, in giving direction to power. A man who can lift a certain object only six feet from the ground with his hands, may, by the aid of a pulley, raise it to the top of a house or a mast, without using a ladder or leaving the spot where he stands. When it is desirable that a door should close of itself when it is opened, a pulley is sometimes fastened to the lintel, and a cord from which a weight is suspended, passed over it. We also use the single pulley to raise the window blinds, and sometimes also the sashes.

There is one case in which power is gained by the single pulley. If we fasten one end of the cord to a chair, in which we are seated, and then draw the other end, we may lift ourselves by exerting enough of strength to lift half our weight under ordinary circumstances. The explanation of this fact is, that while we lift one half of our weight, the pulley sustains the other half; and this explanation will apply to all cases of gain of power in the use of the pulley.

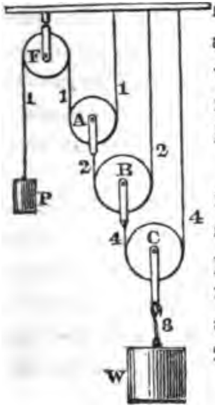


Thus, in this figure, the power at P is raising the weight W, by a cord which is attached at A. The weight is equally sustained at P and A. Therefore P has to lift only half as much as would raise the weight without the pulley. But to raise W one inch, both sides of the cord must be shortened one inch. As this is done on the side of P only, P must draw the cord through 2 inches of space to lift W through 1. Showing again that what is gained in power is lost in time.

When several moveable pulleys are used together, each one, having the cord equally stretched on each side of it, adds as much to the general effect as the power is. So that if there are 4 wheels, the power is four-fold. Thus, A, B, C, and D, each doubling the original effect of P, cause it to balance W, which is 4 times as heavy as P. By means of 20 wheels, P could sustain 20 times as much as its own weight.



There is another kind of pulley, not so generally applicable, but in which the power is multiplied much more rapidly by an increase of the wheels.



This will be understood from the figure. We will suppose the power to be one pound. The wheel A doubles this, making it 2 pounds, as is indicated by the figure 2. Now, B does not merely double the original power, but doubles the power as it is at A. That is, it doubles the 2 pounds, since the cord on each side of the wheel, is drawn by a force of 2 pounds. The power is therefore 4 pounds. It is plain that the wheel C doubles this power, making it 8. P, therefore, balances W, though it is but ⅛ as heavy. By the addition of another wheel the power would be increased to 16, by the addition of another it would be made 32; which shows how easily it might be made enormously great.

Examples of the pulley may generally be seen among the preparations for erecting buildings, and in mines, and at other places where there are many heavy objects to be raised to a considerable height. But they are especially useful on a ship, where they are used for loading, unloading, hoisting the sails, and for other purposes. The preparations for manufacturing them are called Block-machinery, because the block which contains the wheels is the principal part of the pulley.

Some idea may be formed of the importance of this power for maritime purposes, from the following facts: There is machinery for the making of blocks at Portsmouth, in England, invented by Brunel, a celebrated engineer, which cost more than 200,000 dollars. The blocks can be made of one hundred different sizes, and thirty men can, by it, make one hundred in an hour. It is estimated that this machinery, after paying the interest on its enormous cost, and the repairs which it may need, saves the nation, in time of war, more than one hundred thousand dollars a year, by the advantages which it affords for making blocks for the navy.

QUESTIONS.

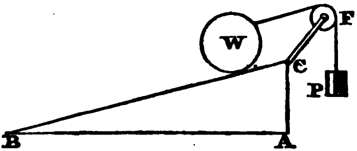
What is the Pulley in its simplest form ?
Of what use is a single pulley ?
In what case, however, is there a gain of power ?
What is the explanation ?
When several moveable pulleys act together, how much loes each add to the effect ?
How much does each wheel add in another kind of pulley lescribed ?
Where are pulleys generally used ?
What is machinery for making them called ?
Why is it so called ?
What is said of the block-machinery at Portsmouth ?

SECTION 5.

THE INCLINED PLANE.

One of the simplest and most interesting of the mechanical powers is the Inclined Plane. This is merely a slope along which a weight may be raised or lowered. The advantage which it gives us in raising a weight is, that we raise it more slowly in proportion as the plane is less inclined; or, simply, as we have seen in all other cases of the mechanical gain of power, we exchange time for power.

Every one who has seen a barrel filled with flour, cider, or other heavy material, raised into a wagon by rolling it up on a plank, instead of lifting it perpendicularly, has seen the inclined plane used as a mechanical power. The ease with which a barrel of a certain weight is raised in this manner, depends on the length of the plank, compared with the height of the wagon.



This may be illustrated by a figure. F is a fixed pulley; P, the power, and W the weight. B C is the inclined plane, and A C its elevation. Now, to balance each other, the power must be to the weight as A C is to B C. That is, if the plane is 5 times the length of its perpendicular elevation, a power of 1 pound will sustain a weight of 5. If B C were only twice the length of A C, P of 1 pound would only sustain W of 2 pounds. If B C were shortened till it only equalled A C, the plane would disappear, and P of 1 pound would only sustain W of 1 pound.

It will be plain to those who reflect on this principle, that when horses have drawn a wagon along a road from the base of a hill to its top, they have lifted it through the whole perpendicular height of the hill; but if the ascent was gradual, the force exerted was distributed through so much time, that the performance may have been quite easy.

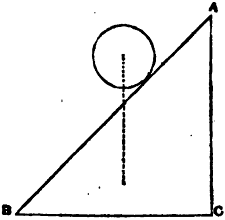
Scarcely any machinery could be made strong enough to lift a train of loaded rail-road cars 100 or 200 feet perpendicularly. But they are raised through an equal height every day by means of inclined planes. A rail-road has been constructed across the Alleghany Mountains, the highest range in Pennsylvania. The cars rise and descend by means of five inclined planes on each side of the mountains. The parts of the road which connect the planes are called levels; and the level which connects the two highest planes is 2490 feet above the sea.

The inclined plane is generally used for ascending elevations. Thus, to rise from one part of a house to another, we use stairs, which are inclined planes divided into steps to prevent our slipping on them. To raise the materials employed in building, to the desired height on the scaffold, either by means of a wheelbarrow, or otherwise, we also use the inclined plane. And to ascend to the top of a high hill or mountain, our only means is the inclined plane.

This will be seen in the representation of the ascent of Mont Blanc, by Saussure, an eminent scientific gentleman of Geneva, with a company of assistants. They had a most difficult and perilous journey, but reached the summit, though it is 15,533 feet high.

We have considered the inclined plane in the character of an ascent. But it has evidently the character of a descent also, and is no less interesting in this respect.

The line of direction of a body, we know, points directly from its centre of gravity to the centre of the earth. Now, when a ball is lying on a level, this line passes through the point at which the ball touches the level; and, therefore, the ball lies still. But when it lies on an inclined plane, the line passes below the point at which the ball touches the plane, as may be seen by the dotted line in the cut. This gives the ball a tendency to fall, as we know from the fact that the centre of gravity seeks the lowest level; and this tendency will be proportioned to the steepness of the plane.



We may now understand the principle, that a body will acquire as great a velocity in descending over an inclined plane of any angle, as it would acquire in falling through the perpendicular elevation of the plane. Thus, in the figure last referred to, the ball would acquire the same velocity in passing from A to B as from A to C.

When we remember in what a rapid ratio the motion of falling bodies is accelerated, we can understand why a wagon let loose on a slope, or a sled moving down a hill-side on snow, moves with a speed which is sometimes ungovernable. The natives of Lapland sometimes descend over the sides of their steep hills on snow-shoes. But to perform this without danger, great skill is necessary.

The principle which we have been considering explains the destructive nature of the avalanche. This is a collection of snow, rolling from a mountain. It is very small at first, but as it rolls along over other snow it increases; and thus constantly growing larger, and acquiring greater velocity during a course of many thousand feet, it becomes perfectly irresistible. In Switzerland, it has sometimes destroyed a whole village.

QUESTIONS.

What is an Inclined Plane?

What is the advantage of it?

What are examples of the inclined plane?

What determines the ease of rolling a weight up an inclined plane?

What is said of horses drawing a wagon up a hill?

What is said of the railroad over the Alleghany Mountains?

For what other purposes are inclined planes used?

In what other character than that of an ascent may the inclined plane be considered?

What is the course of the line of direction of a ball on an inclined plane?

What determines the ball's tendency to roll?

What velocity does a body acquire in descending an inclined plane of any angle?

What does the principle of acceleration explain?

What is an avalanche?

On what principle does its destructive nature depend?

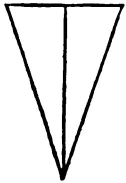
What has the avalanche sometimes effected in Switzerland?

SECTION 6.

THE WEDGE AND THE SCREW.

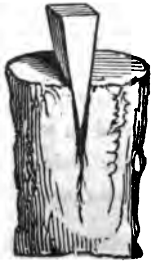
THE WEDGE.

If we wish to raise a weight by means of an inclined plane, the effect will be produced as well by moving the plane as by moving the weight. But when we move the plane we no longer apply that name to it, but call it a Wedge.



If we consider that the principle of the inclined plane is the same whether we apply it horizontally or perpendicularly, we shall see by the representation of a wedge, that it is a double inclined plane.

The wedge is used for a great variety of purposes. All the articles which come under the denomination of cutlery are essentially wedges. Such are axes, chisels, knives, and scissors. In proof of their being wedges, we may observe that the effect of the cutting part of these implements is in proportion to their breadth compared with their thickness. We might state the same in this general way: the thinner the edge the better will the instrument cut. There are limits to this statement in practice, arising from the quality of the materials employed. Thus, a razor will cut much more keenly than a chisel, but if we attempt to cut hard wood with a razor we destroy its edge.

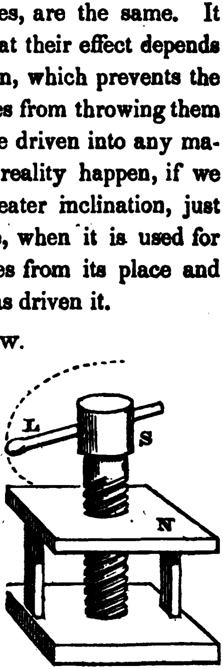


These principles may be observed in the common wedge used for splitting wood. If we make it very thin, its effect on the wood is almost irresistible; but then we are likely to break it to pieces in attempting to drive it.

Pointed instruments, as the awl, the pin, and the needle, are also wedges, though in them the inclination extends through the whole circumference.

The wooden pins used for fastening beams together, are wedges; and common nails, which serve for such a variety of purposes, are the same. It is scarcely needful to add that their effect depends in a great measure on friction, which prevents the pressure on their sloping sides from throwing them back instantly when they are driven into any material. And this would in reality happen, if we gave their sides a much greater inclination, just as a short and thick wedge, when it is used for splitting a log, sometimes flies from its place and injures the individual who has driven it.

THE SCREW.



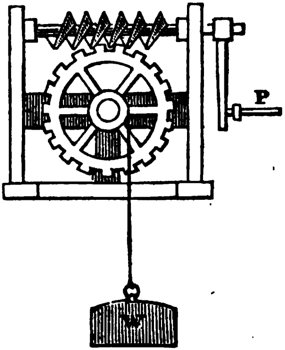
The sixth mechanical power is the screw. This is composed of a cylinder with a protuberance, called a thread, winding around it at an angle determined by the breadth of the thread.

This is sometimes called an external screw, while another, having the thread within, and made to receive this, is called an internal screw, or a nut. Thus, in the cut, S is the external screw, and N the nut, while L is the lever by which the screw is turned.

It was mentioned that the stairs which we use for ascending from one part of a building to another, are inclined planes. In some cases the stairs run circularly from the bottom of a building to i's top. Of this there is a fine illustration presented by the Washington Monument, at Baltimore. It is composed of a base 23 feet high, a column 140 feet high, 20 feet in diameter at the lower end and 14 at the top, which is surmounted by a colossal statue of Washington. This beautiful structure is ascended by means of stairs which wind continuously to the top of the column.

Now these stairs precisely represent the screw, and show that the screw is nothing else than a winding inclined plane. And as stairs, which rise gradually, are much easier of ascent than those which are very steep, so the power of the screw is proportioned to the thinness of the thread; or, in other words, the power increases as the course of the thread approaches to a right angle with the direction of the cylinder.

The thread of a screw is sometimes made to act on the teeth of a wheel, as is shown in the figure. This is called the perpetual or endless



screw, because its operation, unlike that of other screws, may go on in one direction during an indefinite length of time.

In this example we again see that the screw is an inclined plane. For, if we will hold the figure in such a position that P shall be nearest the ground, and imagine the screw to be turned, we shall see that the teeth of the wheel are made to ascend an inclined plane; and that the smaller the angle at which they ascend, or, in other words, the nearer the threads to each other, the greater the power of the screw.

QUESTIONS.

How else may we use the inclined plane, than by moving the weight on it?

When so used what is it called?

What then is a Wedge?

What examples of wedges are mentioned?

What is the rule in regard to the effect of the principles of the wedge in cutlery?

What limits the application of this rule?

What is said of pointed instruments?

What other wedges are mentioned?

On what does the effect of nails depend?

What is a Screw?

What two kinds of screws are there?

What is said of the Washington Monument at Baltimore?

What do the stairs of this structure represent?

To what is the power of the screw proportioned?

When the thread of a screw is made to act on the teeth of a wheel, what is the machine called?

Why is it so called?

What do we see in this example?

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CHAPTER V.

HYDROSTATICS.

SECTION 1.

COHESION—COMPRESSIBILITY—PRESSURE IN LIQUIDS.

NEXT to the air which forms our atmosphere, the most abundant of the tangible materials around us is Water. It not only forms ponds, brooks, lakes, and rivers; but in the form of seas and oceans, it covers nearly three-fourths of the surface of the globe. The Pacific Ocean alone covers more space than all the known continents and islands.

On our knowledge of the nature of this element depends the success of many of our industrial operations; our safety while living near it on land, or sailing from country to country on its bosom; and of making new and unexpected uses of it, which may afford conveniences to ourselves and many other persons.

We generally see water in its liquid form; though sometimes as ice, and at other times as steam. At present we shall only consider it as a liquid. And it may be well to mention that the properties which we shall describe as belonging to it, belong to liquids in general. But we shall confine our descriptions to water, because it is employed more than any other; and if we understand those properties in regard to one liquid, we shall understand them in regard to all others.

One of the properties which distinguish liquids from solids, is, that they yield to the slightest pressure. This might be supposed to prove that they are without cohesion; but such is not the fact. When water collects on glass, or any other smooth substance, or hangs from the under side of any thing, as from the under edge of a board, it does not remain spread out flat, but collects in drops, which are round, except on the adhering side. This shape is always assumed by cohering particles when they can move freely among each other. Thus, if lead is melted to a liquid, by heat, and then thrown from the top of a tower, it assumes the shape of drops, or little globes; and if received in water below, so as to harden without being flattened, it will permanently retain the globular shape. This philosophical experiment is exhibited every day at the various towers erected for the manufacture of shot; for it is the process by which that article is made. The round drops which fall through the air and form rain, are also an example of this.

The weakness of the cohesion of water is illustrated in what we call spray. This is formed when water is dashed against any resisting object, as against a rock on the sea-shore; or when one wave is dashed against another. We also see it when a stream of water is violently thrown into the air, especially if the air is agitated. Thus, when water is thrown to the top of a burning house, from an engine, it is sometimes carried away in spray, by the wind, without affecting the fire.

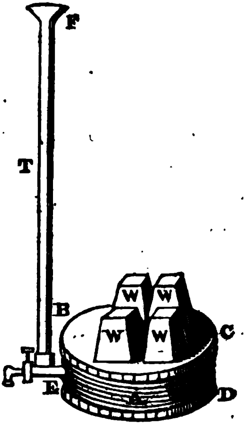
There is a cascade in Switzerland which is formed by a stream that falls over a precipice 800

feet high. The water, in dashing down through the air, becomes a fine white spray; and the cascade is therefore called the Staubbach, or, if translated into English, the Dust-brook.

It was long thought that water is entirely incompressible, and this was supposed to be fully proved by an experiment made by a learned academy at Florence, in 1650. A hollow sphere of gold was filled with pure water. Then a screw was forced into the water, thus subjecting it to great pressure; and it was found that the water, instead of yielding, oozed through the pores of the gold, and collected in drops upon it. This, however, though it confirmed the fact, that water is highly incompressible, did not prove that it is altogether so; for it might have yielded in some measure, and yet been forced through the metal.

But more accurate experiments have since shown that its bulk is lessened by a 24th part, when it is subjected to a pressure of 15,000 pounds on the square inch. It must, therefore, be considerably denser in the deep parts of the ocean than at the surface. At the depth of 93 miles, it would occupy only half as much space as it does at the surface.

One of the results of the weakness of cohesion among the particles of a liquid, is, that when a pressure is exerted on one part of a mass of it, the effect of the pressure extends equally to every part of the mass.



This may be illustrated by the figure of what is called the hydrostatic bellows. B C and E D are boards connected by folds of leather, marked A. T is a thin tube, and F a funnel at its top. If we pour water into F it will run into A at E, and have a tendency to separate the boards, that is, to raise the upper one. The pieces marked W are weights of metal. We will suppose B C to be 1 foot in diameter.

Now, if the weight of a column of water 1 foot in diameter and 20 feet in height were put in communication with the interior of A, its force would evidently be great enough to lift the weights up till the leather would be stretched. But what we wish to arrive at is this: that if a column of 1 foot in diameter will do this, then will a column of the same height lift them, however small may be its diameter.

This is called the hydrostatic paradox, because it seems at first contrary to reason to say that a small quantity of water should, by its weight, produce as great an effect as a large one. It is however true, and a little reflection will explain it. If T is 20 feet high and 1 inch in diameter, then it will be a column of that height pressing on 1 inch of the water in A. Now if the pressure, without being lessened on the first inch, extends equally to every other inch in A, it is clear that it must be equal to the pressure of a column of the same height, and with a diameter as large as that of A.

This principle is applied to what is called the hydrostatic press, which is used for pressing books and for other purposes, and is a machine capable of immense power. For, by increasing the diameter of A and the height of T, we could acquire any power which the materials of the machine would be capable of sustaining.

QUESTIONS.

Next to the air, what is the most abundant material around us?

What does water compose?

Which is the largest body of it in the world?

Of what advantage is our knowledge of its nature ?

In what forms do we see water ?

Why, in considering the properties of liquids, may we confine our remarks to water as an example ?

What is a distinguishing property of liquids ?

Are liquids void of cohesion ?

How is it shown that their particles are cohesive ?

What are two examples of this ?

What is an evidence of the weakness of their cohesion ?

What is said of a cascade in Switzerland ?

What was formerly thought regarding the compressibility of water ?

What experiment was supposed to prove that it is incompressible ?

Did this prove it ?

What have more accurate experiments shown ?

What is one of the effects of the weakness of cohesion in liquids ?

By what apparatus is this illustrated ?

At what principle do we arrive by the aid of the hydrostatic bellows ?

What is this principle called ?

Why is it called the hydrostatic paradox ?

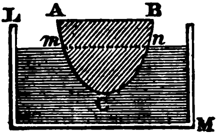
To what is this principle applied ?

SECTION 2.

EQUILIBRIUM—SPECIFIC GRATITY.

We know from observation that when a piece of wood floats on water, it displaces a portion of the water and is then in Equilibrium with it. The portion which it displaced was in equilibrium with the rest of the water before it was disturbed.

As equilibrium is nothing more than equality of weight, we must infer that the floating wood displaces precisely its own weight of water. The same will of course be true of any other body that is not too heavy to float.



To illustrate this, let L M be a cistern, and A B C a floating body. Then the weight of the water displaced by *m n* C, will equal the weight of the floating body.

If we wish to make a body which is heavier than water float, we must make it hollow, so that a part of its bulk, namely, its interior, shall be composed of air. This explains the floating of a porcelain bowl or an iron steamboat.

On the same principle a ship, though made of heavy wood, will not sink far into the water, even when it carries large quantities of merchandise.

Most animals which live on the land are lighter than their bulk of water, and therefore can swim in it; and they can swim with more ease in the sea than in a river, because salt water is heavier than that which is fresh. Fishes are a little heavier than water, and therefore they sink; but they have a little bladder containing compressed air, and when they wish to rise they permit this to expand.

The Specific Gravity of a body, is its weight compared with the weight of an equal bulk of some other body. Thus, a cubic inch of gold is as heavy as 19 cubic inches of water; its specific gravity is therefore 19. To ascertain this, we should weigh the metal first in the air and then in water. In the latter it would weigh $\frac{1}{19}$ less than in the former, in consequence of the displacement of its own bulk of the water.

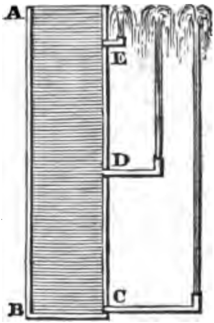
The specific gravity of silver is only 11, and therefore a pound of silver would displace nearly twice as much water as a pound of gold. If we purchased a golden platter or bowl, and suspected its purity, we could thus detect a fraud. This is illustrated by the invention of this mode of weighing bodies.

Hiero, king of Syracuse, had given a workman a certain amount of gold to be wrought into a crown. When it was brought it had the right weight, but the king suspected the workman had kept part of the gold, and in its stead mixed an equal weight of silver with the rest. He therefore applied to Archimedes to know how he might detect the fraud. This puzzled the philosopher during some time: but at length he thought of finding whether the crown would displace more water than its own of gold that was pure. He was in a bath when this thought came into his mind. The bath was quite full of water before he went into it, and he happened to notice that the water which, on his entering, flowed over its edges, must be equal to himself in weight. Seeing the importance of his discovery, he leaped out of the bath, and forgetting, in his exultation, to put on his clothes, he ran home to try the specific gravity of the crown, crying out, on his way, "Eureka!" which means, in Greek, "I have found it."

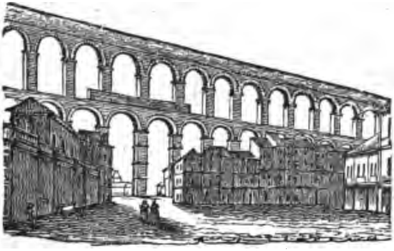
Water always seeks its own level; so that if pipes are laid from one high hill to another through the intervening valley, water will flow from the top of one to the top of another. On this principle towns and cities are supplied with water from neighboring hills, where it is generally contained in reservoirs into which it is forced by machinery from streams below. From these it is led by pipes to the various houses, and frequently to the highest rooms in them.

The fountains which ornament the public squares of many cities, also owe their existence to this principle. For the water, when directed upwards, still has a tendency to rise as high as its source, though permitted to escape from the pipes into the air, as is clearly illustrated in the figure.

The force with which the stream of a fountain rises, shows that the pipes which lead it from the reservoir must sustain a great pressure. This pressure is equal to that of a column of water rising from the pipe, as high as the surface of the reservoir. From what has been said of hydrostatic pressure, it is evident that to lead water from a hill of considerable height would require pipes of very great strength.



This may be the reason why the ancients brought supplies of water across valleys by means of aqueducts, which were enormously expensive. Some of the aqueducts erected by the ancient Romans are still in existence. Such is that of



Segovia in Spain, which is half a mile in length, has 159 arches, and is in one place 94 feet high. It has been thought by some that the builders of these aqueducts were not acquainted with the principle that water led in pipes, as under all other circumstances, will seek its level. But this seems to be a mistake, as there is evidence to the contrary.

And if the construction of aqueducts were sufficient proof, the people of future ages might conclude that this principle was as little known in modern as in ancient times. For in the last century Louis XIV. erected a magnificent structure of this kind at Versailles; and within a few years an aqueduct has been constructed to bring water to New York from the Croton river, at a distance of 41 miles.

QUESTIONS.

What is Equilibrium?

What weight of water does a floating body displace?

How can we make a body heavier than water float?

What does this explain in regard to ships?

Why can most land-animals swim?

Why can they swim more easily in the sea than in rivers?

How can fishes rise in the water?

What is Specific Gravity?

What is an example of this?

What is the specific gravity of silver?

What may the specific gravity enable us to detect?

How was this mode of weighing bodies discovered?

Why will water flow in pipes from the top of one hill to the top of another?

What use is made of this principle?

What is the explanation of fountains?

What is the amount of pressure in the pipes of a fountain?

Of what practice of the ancients may this be the reason?

What is said of the aqueducts of the ancients?

Describe that of Segovia?

Of what principle have some considered the ancients ignorant?

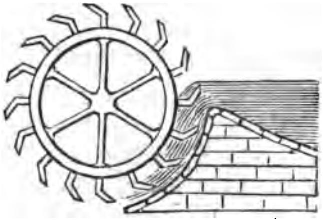
What modern aqueducts are mentioned?

SECTION 3.

FORCE—VELOCITY—FRICTION OF LIQUIDS.

We know from the principle of acceleration that when water falls through the air or runs down an inclined plane, it must acquire great force. It is calculated that the Falls of Niagara would drive all the machinery in the world, and that they waste more power every minute than was expended in building the pyramids of Egypt. And, as another example, it may be mentioned, that during a great storm and flood which took place in Scotland in 1829, the river Don forced a mass of 400 tons of stones, many of them weighing 200 or 300 pounds, up an inclined plane, which rose 6 feet in 8 or 10 yards. A stone of 3 or 4 tons was also moved out of a deep pool in the river, 100 yards from its place.

This power of water is employed to drive a great variety of machinery, and saves a great amount of labor that would otherwise have to be done by men and horses. The most familiar example of its application is the common water-wheel, which is employed in mills for grinding grain, sawing logs, and for other purposes.



It may be supposed that here we have a gain of power without the loss of an equivalent in time. And this is true, but it is because nature has prepared the power for us. The water must of course be raised before it can exert power in descending. If we had first to carry the water up a hill, we should find it a very expensive power for driving mills. But it is carried to the tops of the hills and mountains for us by the clouds, and we have therefore only to take advantage of its descent.

Streams in open beds, or those which are not confined in pipes, must, from the nature of gravitation, seek the lowest level which they can reach, and this is generally the sea. In their course they sometimes descend a great distance. Thus the Rhone, a river of France, descends 1000 feet. According to the theory of acceleration, it should, in this descent, although it makes it gradually over a long region of country, acquire the speed of 170 miles in an hour; for that is the rate at which a body moves which has fallen 1000 feet perpendicularly. But it is so much retarded by friction that it moves only at the rate of 4 or 5 miles an hour.

But though friction offers great resistance to the rapid motion of water, it does not stop it altogether, when the descent is very slight. Thus the Croton aqueduct falls but 1 foot in a mile, and some rivers flow through a distance of 1000 miles with but 500 feet of descent.

Friction is the cause of waves. The air, in moving along the surface of the sea, produces small elevations, and these, as the action of the air proceeds, become very large. At places on the sea, where there is much steady wind, their size becomes enormous. Thus, in sailing round the Cape of Good Hope, waves are seen so large, that a few ridges and depressions fill up the space of a mile.

Franklin, whose mind was constantly suggesting new applications of principles, showed that pouring oil on water agitated by the wind, would cause its waves to subside. This diminishes the friction between the air and water, just as the same material diminishes the friction between solids, as in the case of the axle and nave of a wagon.

QUESTIONS.

What do we know from the principle of acceleration?
What has been calculated in regard to Niagara?
What is said of a flood in Scotland?
For what is the power of running water employed?
What is a familiar example?
How is the gain of power, without the loss of time, in using waterfalls, explained?
What does a stream of water seek?
Where does it generally find the lowest level?

How much does the Rhone descend before it reaches the sea?

According to acceleration, what velocity should it acquire in this descent?

What is its actual velocity?

By what is it retarded?

Does friction stop the motion of water altogether, when its descent is very small?

What is the fall of the Croton aqueduct?

How much is that of some rivers?

What is the cause of waves?

How are they produced?

What effect has oil on waves?

How is this effect produced?

CHAPTER VI.

PNEUMATICS.

SECTION 1.

We have considered the mechanical properties of Solids and Liquids. We will now attend to those of Gases. The branch of science which treats of these is called Pneumatics.

Though there are many liquids, we considered only the properties of water, because when we understand the laws which govern it, we can readily apply them to any other liquid. So, though there are numerous gases, yet, in examining the principles of pneumatics, it will be sufficient to understand them as they are exhibited by the air, for we shall then know how to apply them to all other gases.

The collection of air in which we live, and which surrounds the whole globe, is called the Atmosphere; and, as there may be different kinds of air, we call that fluid which composes the atmosphere, atmospheric air.

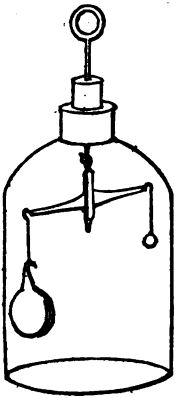
To those who have never considered the nature of air, it may seem strange that we should speak of air as a fluid in which we live. But, though they may think they never saw the air, and may never have thought of it as matter, yet it fills all the space around us that is not occupied by other matter, just as water fills the caverns, and occupies the space around the rocks in the ocean.

To be convinced of this, we have but to consider that the air may be weighed and measured. It has been calculated that a room 20 feet square and 12 feet high, contains, when there is nothing else in it, more than 367 pounds of air. Yet, if a child were asked what it contains, he would very probably say it contained nothing.

We may understand this more clearly if we think of the condition of fishes. It is very likely that they never feel that they are in an element till they spring into the air, or, as we say, out of the water.

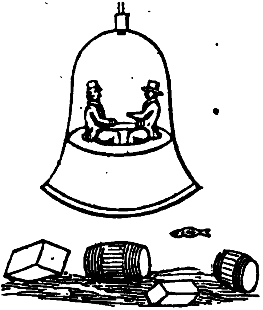
There are many ways of showing that the air has weight, elasticity, and other properties of matter; but the best of them is to try experiments on the air-pump. This instrument is not easily explained unless we have one that we may refer to; and as it is now found in every well furnished school-room, we need merely say, that with it we can pump air out of an air-tight vessel, as we can pump a liquid out of a barrel.

Suppose that we should fill a flask with water, and then try to weigh it, with a pair of scales, in water. It would here weigh nothing, because it would just float in the water around it. But if we take the flask out of the water, we can weigh it. Precisely so with air; we cannot weigh it in air because it will float. But if we attach a quantity of it to scales, and put them into a glass vessel, and pump out the air which filled the vessel, we may easily weigh that which we have put in.



Such a vessel is called a receiver, and when the air is pumped out it is said to be exhausted.

Many interesting experiments, beside the one mentioned, may be tried with an exhausted receiver. We will mention one of them. We said, in a previous chapter, that bodies fall at the rate of $16\frac{1}{12}$ feet in a second. But we know that a piece of money falls much faster than a feather. This is because the feather is supported by the air. In an exhausted receiver it falls as fast as the coin.



The air is impenetrable, as we have already learned. On this principle depends the use of the diving-bell. When it is sunk in water, the water does not fill it, because it contains air; and in this men may breathe during a considerable time. It may, therefore, be employed in performing work under water, or recovering goods which have been lost from the wrecking of ships, or other causes. When the person in the diving-bell is to remain long under the water, fresh air is forced into the bell, at intervals, through hose reaching down from the surface.

QUESTIONS.

What is that branch of science which treats of the mechanical properties of Gases called?

What substance will be suitable to illustrate those principles?

What do we call the collection of air which surrounds the globe?

To what may the occupation of space by air be compared?

What consideration will convince us that air is positively matter?

What has been calculated in regard to the air contained in a room 20 feet square?

What is probable of fishes?

What is the best way of showing the properties of air?

What may be done with the air-pump?

How may air be weighed?

What is the vessel, in which this may be done, called?

What experiment, that may be performed with a receiver, is mentioned?

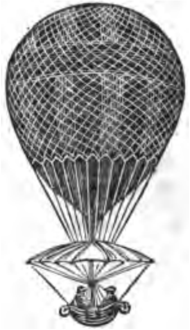
On what property of air does the diving-bell depend?

For what is it used?

What is done to enable a person to remain a long time under water in the diving-bell?

SECTION 2.

If we fill a bladder with air and put it into water, it will immediately rise to the top if we let it go. This is because air is lighter than water. Now, if we fill a very light sack with any material lighter than the air and let it go, it will immediately rise to a height proportioned to its lightness. There are several gases lighter than atmospheric air; as, for instance, hydrogen. If then we make a large sack of air-tight canvass, and fill it with hydrogen gas, it will not only rise in the air, but carry with it as many pounds as it wants of equalling in weight its bulk of air.



This explains to us the principle of the Balloon, which has been used frequently during some years for making ascensions in the air to promote science, or to gratify curiosity. It was invented in 1783, by Stephen and Joseph Montgolfier, of Annonay, in France. They filled their balloons with hot air, which rises in cold air, because the heat expands it. It seems, however, that they did not understand the principle on which their balloons rose, but thought they were raised by the smoke of the fire which they employed to heat the air.

The atmosphere is supposed to be about 45 miles in height. From the elastic nature of the air, we know that its density must decrease with the increase of its height; for those portions which are lowest bear the greatest weight, and are consequently pressed together the most closely. Its difference of degree of density is so great that the part of the atmosphere which is within 3½ miles of the earth contains as much air as the part above it. This can be verified by ascending high mountains. We there find the air so rare, or expanded, that breathing is difficult.

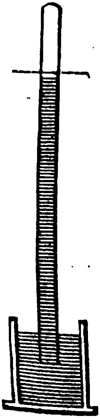
Near the earth 100 cubic inches of air weigh about 31 grains. This may not seem much, but when we consider the extent of the atmosphere, we may be prepared to believe the statement, that the whole of it weighs as much as would a globe of lead, 60 miles in diameter. Every part of the earth's surface of course supports a column of air as high as the whole atmosphere, and the weight of this is found to be 15 pounds on every square inch.

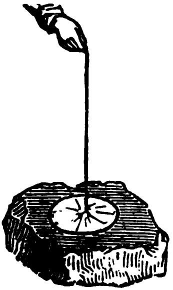
As the pressure of fluids acts equally in every direction, every part of the surface of an object in the air must bear this weight. The surface of a man's body is about 2000 square inches, or something more than 14½ square feet. The pressure of the air on his body must then be 30,000 pounds, or more than 13 tons.

It is true we do not feel this pressure, but this is because air or other fluids pervade all parts of our bodies. If we tie a piece of bladder over a glass vessel, as is shown in the cut, and pump the air out with the air-pump, the weight of the air will break the piece of bladder with a loud noise.

A column of air as high as the atmosphere, weighs about as much as a column of water 33 feet high. Now, if a long pipe is put into water, and the air pumped out of it, the pressure of the air outside will force the water into the pipe to the height of 33 feet. This explains the nature of the pump, which is nothing more than such a pipe put into water.

Mercury is about 13½ times heavier than water. A column of mercury, therefore, about 30 inches high is as heavy as the atmosphere. Now, on the principle already explained, if a pipe free from air is put into mercury, the fluid will rise in it about 30 inches. Such a pipe, having explanations connected with it, is called a Barometer. The atmosphere is heavier at some times than at others, according to the state of the weather. When light, it will, of course, not sustain so high a column of any fluid as when heavy. On this account the rising and falling of the barometer are indications of the condition of the atmosphere.

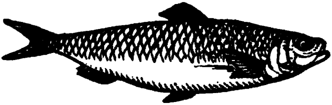




The pressure of the atmosphere explains why a piece of wet leather, put on a smooth stone, and the air pressed out from between them, adheres so strongly that considerable force is required to separate them.

When birds and insects fly, they lift themselves by using their wings as levers. The air serves as a support or fulcrum for these levers. As the air is light and yielding, their levers must have a large surface. This is the reason why those which have large wings fly with so much more ease than those which have small ones in proportion to their bodies. This is illustrated by the butterfly, which hovers on its wings as easily as it rests on its feet.

The fins of the fish serve the same purpose; but as water is nearly as heavy as the fish, and offers much greater resistance than air, fins are much smaller, in proportion to the animals which use them, than wings.



QUESTIONS.

Why will a bladder, filled with air, not sink in water?

What will any substance, lighter than air, do if set free?

What substances are there lighter than air?

What will occur if we fill an air-tight sack with hydrogen gas?

What weight will such a sack carry?

Of what does this explain the principle?

For what purpose has the balloon been employed?

When, and by whom was it invented?

With what did they fill their balloons?

What seems to have been their idea of the balloon's rising?

What is the supposed height of the atmosphere?

What do we know from the elastic nature of air?

How great is the difference in the degree of its density?

How may this be verified?

What is the weight of air?

How much does the whole atmosphere weigh?

What is the weight of the atmosphere on every square inch?

Of what extent is the surface of a man's body?

What then is the atmospheric pressure on it?

Why do we not feel this pressure?

What simple experiment illustrates this?

How does a column of the atmosphere compare in weight with a column of water?

What will result if a long pipe is put into water, and the air pumped out of it?

Of what does this explain the nature?

How much heavier is mercury than water?

How high will it rise in a pipe free from air?

What is such a pipe called?

Why are the rising and falling of the barometer indications of the state of the atmosphere?

What does the pressure of the atmosphere explain?

How do birds fly?

In what manner does the air serve them?

Why must their wings have a large surface?

What does this explain?

By what is this illustrated?

What part of fishes corresponds with the wings of birds?

Why are fins smaller than wings?

CHAPTER VII.

OPTICS.

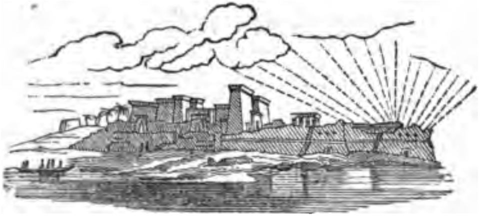
SECTION 1.

PROPERTIES OF LIGHT.

LIGHT is one of the most interesting and universal agents in nature. Without it we could never discover the beauty of the world which we inhabit, nor the existence of the millions of other globes which revolve in space on every side of us.

During the day we generally have so abundant a supply of light, that we forget its value. But when night covers the whole landscape, we feel how desolate the world would be if we could have no sun and no lamps to shine.

When light is introduced into a dark place, it produces so great a change that it almost seems to give all things on which it shines a new existence. This may be observed when a lamp is lighted in a dark room; but we have a still finer illustration of it when the light of morning reveals to us cities, hills, fields, and waters. This is felt with especial force by those travellers who sometimes spend the night among deserted ruins.



Sunrise.

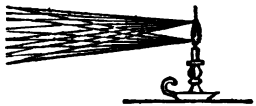
There are two theories of light; and it is not possible, in the present state of science, to decide which of them is true. One is called the Corpuscular theory; and according to it, light consists of minute particles of matter of a peculiar kind, which emanate or fly off from luminous bodies. This theory was adopted by the great philosopher Newton.

The other is called the Undulatory theory; and it teaches, that light consists of minute waves, put in motion by luminous bodies in some highly elastic fluid which pervades the universe. This theory was adopted and greatly improved by Huygens, a distinguished philosopher of Holland, and is advocated by many of the most eminent writers on science.

One reason why we cannot decide between these two theories is, that whether light consists of particles of matter or waves in a fluid, they are too small to be detected by our senses. Another is, that nearly all the mechanical properties which light is known to possess, can be explained equally well by either theory.

One of the laws or principles of light is, that it moves in straight lines. This explains why we cannot see around the corner of a house, nor through a bent tube.

A necessary result of this law is, that the rays of light, as they proceed from a luminous body, diverge, or are separated. This is illustrated by the annexed figure, which represents them as proceeding from a lighted candle.



If we consider this principle, we shall understand that the intensity of the light, or, in other words, the quantity which falls on a given space, must decrease as the squares of the distance increase. That is, the light which, issuing from one point in the flame of the candle, is spread through an inch at the distance of a foot from the candle, would, at the distance of two feet, be spread though four inches. A planet, therefore, which is twice as far from the sun as another, can only receive one-fourth as much light, and so of all other proportions.

Light moves with an astonishing swiftness. By observing the eclipses of the satellites of Jupiter, at times when they are near us, and again when they are distant from us, it is determined that light moves about 192,000 miles in a second. This is about equal to travelling around the earth eight times. The light which comes from the sun to the earth, passes through a space of 95,000,000 of miles, and it therefore requires eight minutes to reach us, or it passes through 12,000,000 of miles in a minute.

This may seem incredible at first, but if we consider through what immense distances it must travel, its velocity will scarcely seem sufficiently great. It occupies whole years in reaching us from some of the nearest fixed stars; and Sir William Herschel believed that the light from the farthest nebulæ which he saw through his large telescope, could not reach us in less than 2,000,000 of years.

QUESTIONS.

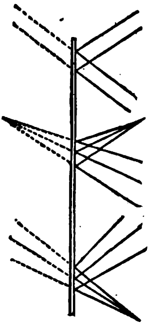
What is one of the most interesting agents in nature?
What could we not discover without it?
What causes us to forget the value of light during the day?

What would be the state of the world without it?
What is the effect of light when introduced into a dark place?
How many theories of light are there?
What is the first?
What great philosopher adopted this theory?
What is the second theory?
Who adopted and improved this theory?
What is one reason why we cannot decide between these two theories?
What is another?
What is one principle of light?
What does this explain?
What is a necessary result of this principle?
At what rate does the intensity of light decrease?
How does this operate in respect to the planets?
How is the velocity of light determined?
How great is it?
How far does light travel in coming to us from the sun?
How far in a minute?
What consideration will make this fact seem credible?
What is mentioned in regard to Sir William Herschel?

SECTION 2.

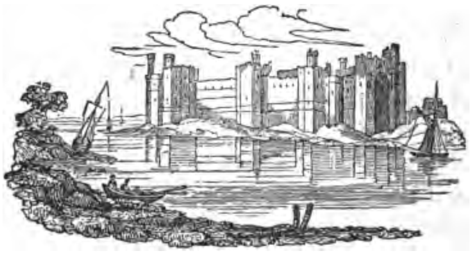
PROPERTIES OF LIGHT—*Continued.*

When light, in its course, strikes any object, a part passes into it, or is absorbed by the object, and a part rebounds, or is reflected. If the part which is reflected strikes the object perpendicularly, it flies back in the line in which it came. But if it strikes it obliquely, it flies off obliquely in the opposite direction. The angle at which it strikes is called the angle of Incidence. We therefore say the angle of incidence and the angle of reflection are equal.



The qualities of the looking-glass, or what is technically called a plane mirror, depend on this principle, as we may see by examining this figure. When we see ourselves in the mirror, the light proceeding from our bodies strikes the mirror and is reflected. A part of it reaches our eyes, and, as we cannot see the rays reflected, they seem to come from an image of us beyond the reflecting substance.

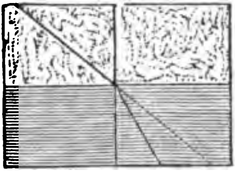
We may see this principle illustrated if we stand on the bank of a river and look at the opposite side. There seems to be within the water a reversed image of every building and other object



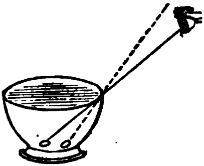
which stands near it. That this is caused merely by reflection, and that there is no such image where it appears, we know from the fact that there is no water under those objects, but only sand or clay, or perhaps solid rock.

We have mentioned that light moves in straight lines. This, however, is only the case while it moves in a medium of uniform density, such as it may possibly pass through in coming from the sun to our atmosphere.

When it passes from a rarer to a denser medium, it is bent towards the perpendicular direction, except when it is moving perpendicularly. Such an effect of course cannot then take place; for if its course is once perpendicular, it cannot be more so. When it passes from a denser into a rarer medium, it is bent towards the horizontal direction. We may see this illustrated in the cut, of which the upper half may be supposed to represent air, and the lower half water.



This may be observed if we place a straight rod partly in water. It will seem so bent that we might suppose it to be broken. Or if we put a coin into an empty bowl in such a position that we can just



see it over the edge, and then pour water into the bowl, the coin will seem to move forward and upward, though it has really not been disturbed.

This quality of changing its course on passing through mediums of different density, is called the Refraction of light. The cause of refraction is not clearly understood, but it is usually attributed to attraction.

QUESTIONS.

When light strikes an object, what is the result?

In what direction is light reflected?

What is the angle at which light strikes called?

What is a general principle in reflection?

On what do the qualities of the mirror depend?

Why do the rays seem to come from beyond the reflecting surface?

What illustration is mentioned?

What proves that this is caused by reflection?

In what case only does light move in straight lines?

How is light bent in moving from a rarer into a denser medium?

What is the exception to this?

How is it bent in passing into a rarer medium?

What illustrations of this principle are mentioned?

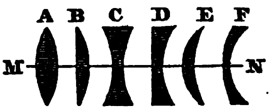
What is the quality of light under consideration called?

What is its cause?

SECTION 3.

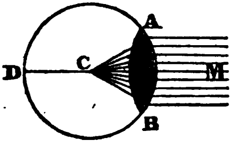
PROPERTIES OF LIGHT—*Continued.*

MANY of our most useful optical instruments depend on the refraction which light undergoes when passing through a Lens. This is a piece of glass or other transparent substance, which is either thicker or thinner at its edge than in the middle. This may be understood if we consider the cut as representing a number of lenses of different shapes, placed edgewise.

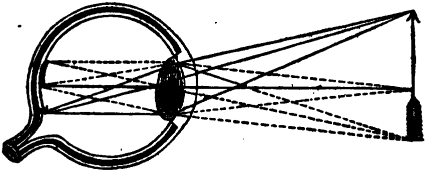


All the lenses generally used are represented here. They have different names, according to their shape. A is a double-convex lens. B is plano-convex, C double-concave, D plano-concave, E meniscus, and F concavo-convex. The line M N represents the Axis of each lens.

The lens is so shaped that it bends those rays which pass through it into a particular direction, and thus makes the object appear either large or small. This is shown in the annexed figure. M represents the rays before they reach the lens, A B the lens, and C the point at which the rays meet. This point is called the focus, and the rays form

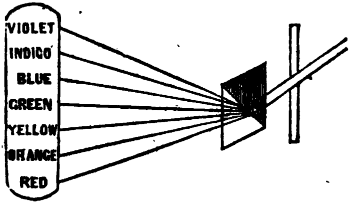


in it an image of the object from which they proceed. If the lens A B were flatter, the rays would meet at D instead of C, and form an image there. This explains the nature of the eye. The rays pass through a lens in the front part of the eye, and paint an image of the object from which they come, on the Retina in the back part, as is shown in the figure.

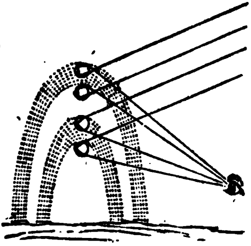


Spectacle-glasses are lenses; as are also the glasses of telescopes, used for examining distant objects, and microscopes, used for examining minute ones.

When light is refracted by a triangular piece of glass, called a prism, the rays are separated according to their different colors, those of a particular color being thrown into a particular direction. We thus find that there are seven kinds of light, subject to different degrees of refraction, as they are represented in the cut.



This explains the nature of the Rainbow. The drops of rain, acting as lenses, refract the light while they are falling, and hence we see the different colors separated. The rays, however, are not only refracted. When they enter the rain-drops on one side, they are reflected from the other. There are generally two rainbows visible at once. In the outer rainbow the rays are reflected twice, in the inner one only once; and as at each reflection a part of the light is lost, the outer rainbow is fainter than the inner one.



Twilight is caused by the reflection and refraction of light in the atmosphere. The general blue color of the atmosphere, and its red hues in the morning and evening, depend on the same principles. The Mirage, which is a representation of water and other pleasant objects in deserts, is caused also by these, as are many other curious phenomena.

QUESTIONS.

On what do many optical instruments depend ?
What is a Lens ?
What different lenses are mentioned ?
What is the effect of a lens ?
What is a focus ?
What is formed in the focus of the light ?
How is the eye explained ?
What effect has a prism on rays of light ?
How many kinds of light are there ?
What are their colors ?
In what order do they occur ?
How is the rainbow explained ?
What besides refraction do the rays of light undergo in the rain-drops ?
Why is the outer rainbow fainter than the inner ?
What is the cause of twilight ?
What other phenomena depend on reflection and refraction ?

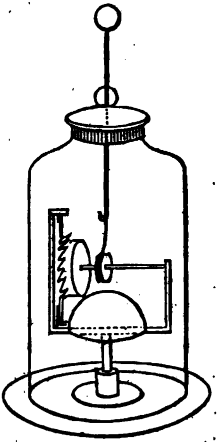
CHAPTER VIII.

ACOUSTICS.

SECTION 1.

NATURE, VELOCITY, EXTENT OF SOUNDS—BELLS.

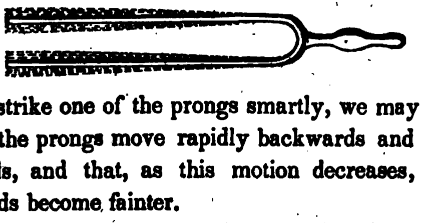
The agent on which, with the exception of light, we most depend to inform us what is occurring around us, is that property of bodies called Sound. The science which treats of sounds is called Acoustics.



The sound of a body is a quick vibration of its particles, which, being communicated to our ears by means of air or some other material, gives us the sensation of hearing. That sounds are vibrations, and not particles emitted by the sounding bodies, is proved by the fact that dense materials convey sounds better than rare ones, and that a body struck in a vacuum produces no sound whatever.

This may be proved by putting a bell into the receiver of an air-pump, as shown in the preceding figure; and having exhausted the receiver, striking the bell by means of a rod moving air-tight in the top of the vessel. If the experiment is rightly performed the bell can scarcely be heard; and would, if the vacuum were complete, be entirely inaudible. On the tops of high mountains, where the air has less density, sounds are much fainter than in lower situations.

But this theory does not depend merely on inference. We may often see the vibrations of a sounding body. If we take the tuning-fork, which is used by musicians for tuning their instruments, and strike one of the prongs smartly, we may see that the prongs move rapidly backwards and forwards, and that, as this motion decreases, the sounds become fainter.



The vibrating body produces in the air a succession of waves, which move through it like those which we see on the surface of water; but they are exceedingly minute. Their number determines what is called the Pitch of the sound, that is, its quality of being high or low. A vibration which produces less than 32 waves in a second, is too low to be heard; and the highest which are ordinarily heard, cause about 12,000 in a second. There are no doubt many sounds produced around us which we cannot hear, because they are too low or too high.

Sound moves in the air at the rate of 1125 feet in a second. We may, therefore, by observing the difference of time between the arrival of the light and the sound, estimate the distance of a thunder-storm, or of a cannon which we see discharged. Suppose that the flash is seen 15 seconds sooner than the sound is heard. Then the distance is 15 times 1125, or 16,875 feet; that is, about 3¼ miles.

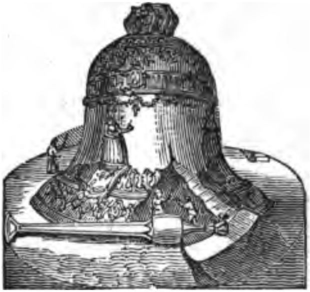
Since density is favorable to the transmission of sound, it is conveyed farther and more rapidly by liquids than by air. Thus, in water a sound can be heard much farther than in the air, and travels 4808 feet in a second. This is also illustrated by the fact that moist air conveys sounds better than dry air, as we know from the distinctness with which we hear distant sounds in damp weather.

Solids convey sound still better than liquids. By applying the ear to a long rod or board, we may hear the ticking of a watch or any slight noise made at the other end. When Indians, or other barbarous people, wish to discover the approach of enemies, they apply their ears to the ground. It has been found that iron conveys sound at the rate of 11,865 feet in a second.

Sound, like light, moves, till obstructed, in straight lines, and in every direction from the body which produces it. A clap of thunder, therefore, or an explosion of gunpowder, often fills hundreds of cubic miles of the atmosphere with vibrations. The discharge of cannon at the battle of Bunker Hill, was heard at Pittsfield, 120 miles distant; and, as water is more favorable to the spreading of sound than the uneven surface of land, naval engagements have been heard at nearly twice that distance.

Among the most common instruments used for producing sounds, are bells. These were known in very ancient times. They were worn upon the robes of the high priests, among the ancient Jews, and the Greeks used them in their camps and garrisons. Church-bells were invented by Paulinus, bishop of Nola, in Campania, about the year 400. They were formerly baptized, that they might be endowed with the power of allaying storms and driving away evil spirits, on being rung. They are sometimes made very large. The great bell of St. Peter's Church, in Rome, weighs 18,607 pounds. Great Tom, of Christ Church, Oxford, weighs 17,000. It was named after Thomas à Becket, who was archbishop of Canterbury in the twelfth century.

The largest bell in the world is at Moscow, in a broken condition. It is 67 feet in circumference, and weighs 443,772 pounds. It is said to have been suspended in a wooden tower formerly, and to have been broken by the water thrown upon it when the tower was on fire.



QUESTIONS.

On what, next to light, do we depend most to inform us of what is occurring around us?

What is the science which treats of Sounds called?

What is a sound?

What proves that sounds are vibrations?

By what experiment may this be shown?

What is known of sounds on the tops of high mountains?

What experiment will enable us to see the vibrations which produce a sound?

How does the vibrating body act on the air?

What determines the pitch of a sound?

What is the pitch of a sound?

What kind of vibration is the lowest that we can hear?

What kinds are the highest that are ordinarily heard?

Do we hear all the sounds which are produced about us?

Why are some of them unheard by us?

At what rate does sound move in the air?

How may we estimate the distance of a thunder-storm, or a cannon which we see discharged?

Why is sound conveyed farther and more rapidly by liquids than by air?

How fast does it travel in water?

By what fact is this illustrated?

Do solids convey sounds well?

What two facts illustrate this?

How fast does iron convey sounds?

In what direction does sound move?

What extent of air does a clap of thunder or explosion of gunpowder often fill with vibrations?

At what distance was the discharge of cannon at the battle of Bunker Hill heard?

Why have naval engagements been heard still farther?

What are among the most common instruments used for producing sounds?

What ancient uses of bells are mentioned?

By whom and when were church-bells invented?

What is the weight of the great bell at St. Peter's Church, in Rome, and Christ Church, at Oxford?

Where is the largest bell in the world?

What are its circumference and weight?

SECTION 2.

ECHO—MUSIC.

When a sound strikes a body it is reflected, and it thus produces what is called an Echo. The reflection takes place on the invariable principle, that the angle of reflection and the angle of incidence are equal. To hear the echo well, we must, therefore, stand directly opposite the reflecting surface. If concave, the surface will reflect better than if straight, for it then throws the vibrations into a focus; and the echo may thus be louder than the original sound.

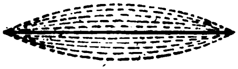
As sound moves 1125 feet in a second, we may estimate the distance of an object by the echo which it causes. The sound must first travel to it, then back; and if this requires one second, it is, of course, distant the half of 1125, or 562½ feet. In this way we may judge of the width of rivers, as their banks in many places produce echoes.

Some situations are so favorable for the reflection of sound, that the echo is repeated many times. An echo, near Milan, is mentioned as repeating the report of a pistol 60 times; and one at Rosneath, near Glasgow, is said to repeat three times completely and distinctly, a tune played with a trumpet. The peculiar sound heard in sea-shells is an echo of the sounds which are about us at the time; and the rolling sound of thunder is supposed to be caused by reflections from different masses of clouds.

Without the aid of science, echoes seem very mysterious. We need not wonder that uninstructed people, and the poets, have always imagined them to be endowed with life. The natives of Cuba, when Columbus was among them, thought that echoes were answers made by their departed friends. Some of the ancient poets say that Echo was a maiden who, roving in the woods, saw Narcissus, a beautiful youth, and loved him; but being slighted, she pined away till only her voice was left. Shakspeare calls echo, "The babbling gossip of the air."

When we cause agreeable sounds to succeed each other in a certain order, we produce Music. These sounds are called notes, and they differ from each other in pitch, which, as we have seen, depends on the duration of their vibrations. The number of notes, from some cause, not well understood, is limited to seven. When we have produced these, we can only proceed by repeating them; and the only difference between the first seven and the second seven, is that one set is shriller, or has a higher pitch than the other. The notes, arranged in their order, form the musical Scale.

When a stretched string or wire is drawn aside and suddenly let go, it vibrates and produces a sound, the pitch of which depends on the tenseness of the string; because the more tightly it is stretched the more rapid will be its vibrations. This explains why the violinist can, by turning the keys, and thereby, tightening the strings of his instrument, give the tones the proper pitch.



Shortening the string, or the distance between its points of suspension, is another means of increasing the rapidity of its vibrations. The string is in this respect like a pendulum; and on this account performers on the violin and guitar, put their fingers on the strings and shorten the vibrating part in proportion to the height of pitch which they wish to give the notes.

In wind-instruments, as the flute and trumpet, the vibration is not produced by strings, but by the column of air contained within the instrument; and as the pitch depends on the length of the column, the performer lengthens and shortens it by means of keys, or by using his fingers as keys.

Music was known as an art to the nations of antiquity in very early ages, but their instruments and tunes were few and simple. Within the last few centuries, much attention has been paid to it. It has received great improvements, and is now an interesting and comprehensive science.

QUESTIONS.

What occurs when sound strikes a body?

What is the reflection of a sound called?

On what principle does it take place?

Where must we stand to hear an echo well?

Why does a concave surface reflect sound better than a straight one?

How may we estimate the distance of an object?

In what manner must the estimate be made?

What two remarkable echoes are mentioned?

How is the sound in a sea-shell explained?

How is the rolling sound of thunder explained?

What idea of echoes had the Cubans when Columbus was among them?

What account did some of the ancients give of the echo?

What did Shakspeare call it?

How do we produce music?

What are the sounds by which it is produced called?

How do they differ from each other?

What is the number of musical notes?

When we have produced the seven, how can we proceed in producing notes?

What will be the difference between the first seven and the second?

What do the notes arranged in their order form?

On what does the pitch of the sound of a vibrating string depend?

What does this explain in regard to the violin?

What is another means of increasing the rapidity of the vibrations of a string?

How do performers on some stringed instruments apply this principle?

How are the vibrations produced in wind-instruments?

What was known of music in ancient times?

What is its present condition?

A GLOSSARY

OF TERMS USED IN THIS WORK.

Acceleration. An increase of the velocity of bodies in motion.

Acoustics. The science of sounds.

Agent. Anything that has the power to act on another object.

Air-Pump. A machine used for pumping air out of a vessel.

Angle. The space between two lines which meet in a point; the point at which two lines meet.

Aqueduct. A structure erected to convey water from one place to another.

Arch. A structure made of blocks of a hard material, arranged in the form of a bow, and supporting each other by their mutual pressure.

Architecture. The art of building.

Art. The practical method for effecting an object, and the system of rules which govern that method.

Atmosphere. The collection of fluid which envelops the globe.

Atom. A portion of a substance too small to be divided.

Attraction. The supposed power in bodies which draws them together.

Axis. The line about which a body revolves.

Axle. The shaft or pivot on which a body revolves.

Barometer. An instrument for measuring the weight or pressure of the atmosphere.

Base. In geometry, the lowest side of a figure; in architecture, a body which bears another.

Brittleness. The condition of being easily broken.

Capillary Attraction, (Lat. *capillus*, a hair.) That species of attraction which causes fluids to rise in fine or hair-like tubes.

Capstan. A strong cylinder, used for raising heavy articles, particularly on ships for raising anchors.

Centre of Gravity. That point which is in the centre of a body in reference to its weight. If a plane passing through its centre of gravity divides a body, the two parts, whatever may be their shape, will be of equal weight.

Circumference. The line which forms the boundary of a circular body.

Cloud. A visible collection of vapor suspended in the atmosphere. It differs from mist in being elevated considerably above the ground.

Cohesion. That force of attraction which causes the particles of homogeneous bodies to resist separation. Adhesion is the force with which bodies of different substances adhere to each other.

Collision. The forcible meeting of bodies, caused by the motion of one or both of them.

Colossal. Being huge; or like the Colossus of Rhodes, which was a statue 100 feet high, or, according to the testimony of some writers, still higher.

Column. A support consisting of a base, a shaft, and a capital, and used in building.

Compressibility. That quality in virtue of which all bodies may be forced into a smaller space than they occupy.

Corpuscular, (Lat. *corpusculum*, a small body.) Composed of, or relating to atoms or small particles.

Cube. A body bounded by six equal sides.

Cubic. Having the shape of the cube, or being equal in length, breadth, and thickness.

Density, (Lat. *densus*, thick.) Compactness of constituent particles.

Diagonal. A line drawn across a figure between two opposite angles.

Diameter. A line passing through the centre of a circle or circular body, and touching the parts of the circumference most distant from each other.

Dimensions. The measures or distances through a body, which show its size, that is, its length, breadth, and thickness.

Divergent. Tending from each other, as two lines not parallel, and running from the same point.

Divisibility. The property of being separable into parts.

Dome. A concave structure placed on a building.

Ductility. The property in consequence of which bodies may be drawn out or lengthened without a visible separation of their particles.

Earthquake. An agitation of the earth, supposed to be caused by gases evolved by internal heat.

Echo. A sound repeated to the ear by a reflecting surface.

Economy. The animal economy is the regular operation of nature in the creation and preservation of animals.

Elasticity. That property of bodies by which they recover their shape, when a force that has operated upon them ceases.

Element. A substance which is not compound, and can therefore not be reduced to a simpler condition. The elements are therefore considered the original constituents of bodies.

Exhaust. To exhaust a receiver is to draw the air out of it.

Explosion. The sudden and violent expansion of the parts of an object, generally from the effects of heat.

Extension. The property of a body by which it occupies a portion of space.

Figure. The shape of a body, or the representation of it by a drawing.

Flexibility. The quality of yielding to a force by bending.

Focus. The point of concentration, as that to which sound is thrown by reflection, and light by reflection or refraction.

Friction. The resistance to motion caused by the rubbing of surfaces.

Fulcrum. The point about which a lever moves.

Globule. A little globe or small spherical particle of matter.

Gravity. The weight of a body, or its tendency to approach another body.

Homogeneous. Composed of only one element.

Horizontal. Being level with, or having the direction of the horizon.

Hydrogen. A very light kind of gas, about 14½ times lighter than atmospheric air.

Hydrostatics. The science which explains those properties of water which have reference to its motions or equilibrium.

Impenetrability. That property of bodies which prevents two of them from occupying the same space at the same time.

Incidence, (Lat. *incido*, I fall upon.) The striking of a body against another.

Inertia, (Lat. *iners*, slothful.) Indifference to rest or motion.

Lens. A transparent body having one or both of its sides concave or convex, and used for refracting light.

Lever. A rod resting on a support and used for applying force.

Luminous. Emitting light.

Malleability. Susceptibility of extension from the blows of a hammer.

Mass. The quantity of matter of which a body is composed.

Matter. That species of existence of which we can take cognizance by the senses.

Mechanics. The science which treats of the forces produced by the external action of bodies on each other.

Medium. The matter in which a body exists or through which it moves.

Mercury. A metal which is 13½ times heavier than water, and freezes at a temperature of 40° below zero.

Microscope. An optical instrument used for examining objects too small to be seen by the naked eye.

Mirror. A smooth body capable of reflecting images.

Motion. The act of changing place.

Music. The science which treats of the combining of agreeable sounds.

Naval, (Lat. *navis*, a ship.) Relating to ships.

Nebulæ, (Lat. *nebula*, a cloud.) Portions of matter among the fixed stars, which have a cloudy appearance, and some or all of which are clusters of stars.

Note. In music, a definite sound, or the character which represents it.

Optics. The science of vision.

Orbit. The circular path of a heavenly body.

Particle. One of the smallest parts into which a body can be mechanically divided.

Pendulum. A suspended body which divides time into equal spaces by its vibrations.

Perpendicular. Being at right angles with the horizon, or in a direction differing as much as possible from the horizontal.

Physical. Relating to external nature.

Physiological. Relating to living nature.

Pitch. The degree of acuteness or graveness of a sound.

Pneumatics. The science which teaches the mechanical properties of elastic fluids.

Pores. The spaces between the particles which compose bodies.

Porosity. Having the particles separated by openings or pores.

Power. A force or machine for producing motion.

Principles. Those general truths in accordance with which things exist.

Prism. A transparent substance used for separating rays of light according to the different colors of which they are composed.

Property. That which exists as an attribute of something.

Pulley. A wheel over which a cord is passed, for increasing power or giving it a desired direction.

Pyramid. A figure or body having a square base, and sides which meet in a point. It is supposed to be so called from its resemblance to the shape of a flame.

Quadrupeds [illegible] four feet.

Rare. Having large spaces between the particles; not being dense or compact.

Ray. A line formed by light in the direction of its motion.

Receiver. The vessel of an air-pump.

Reflection. The act of rebounding from a body.

Refraction. The changing or breaking of the direction of a body in motion.

Resistance. A force acting in opposition to another force.

Resolution. The separation of things into their constituent elements. The resolution of forces is the abstract separation of them in calculations.

Rest. The state of freedom from motion.

Retina, (Lat. *rete*, a net.) The expansion of the optic nerve in the back part of the eye.

Rigidity. Resistance of a body to a change of form.

Sapphire. A very hard precious stone.

Satellite, (Lat. *satellus*, an attendant.) In astronomy, a body which revolves round another.

Scale. A progressive series, or a measuring instrument.

Science. Knowledge reduced to a system.

Screw. A spiral ridge or groove winding round a cylinder, and forming one of the mechanical powers.

Sound. The sensation of hearing, or the vibrations which produce the sensation.

Space. Extension considered without reference to matter.

Species. A kind or class.

Specific. Distinguishing: the specific gravity of a body distinguishes it as differing in gravity to a particular extent from a standard.

Substance. That which has independent existence, as distinguished from a property or quality, which must belong to something.

Surface. The outside of a thing: the surface has length and breadth, but no thickness.

Telescope. An optical instrument for viewing distant objects.

Tenacity. The disinclination of the particles of a substance to separate.

Tenseness. The state of being stretched.

Theory. A system of principles belonging or supposed to belong to a science.

Thermometer. An instrument for measuring variations of heat.

Time. Duration limited and measured by the revolutions of the heavenly bodies, and other natural occurrences, or by artificial arrangements.

Transmission. The act of sending through an object, or from one place to another.

Transparent. Permitting the passage of light between its particles, so as not to obstruct vision.

Triangle. A figure which has three angles.

Undulatory, (Lat. *undulatus*, made like waves.) A term applied to that theory which considers light as progressing in the manner of waves.

Vacuum. A portion of space containing no matter.

Velocity, (Lat. *velox*, swift.) The rate of the motion of a body.

Vibration. The backward and forward motion of a susdended body.

Volume. The capacity of a body for occupying space, as distinguished from its mass, or the matter it contains in a given space.

Wedge. A mechanical power, sometimes used for lifting bodies, but generally for forcing their parts asunder.

Wheel. A circular body used for overcoming friction.

Wheel and Axle. A mechanical power composed of a wheel and an axle, with a cord passing over them.

Zero. The point at which the graduation commences in thermometers. In Fahrenheit's thermometer, zero is 32° below the freezing point of water.

THE END.